THE
GEOLOGICAL MAGAZINE
VOLUME LXV.

No. XII.—DECEMBER, 1928.

ORIGINAL ARTICLES.

Studies in the Variation of *Batillaria pleurotomoides* (Lam.).

By T. Hudson Rowlands, M.Sc., University College of Swansea.

RECENTLY Mr. A. Stuart (1927, pp. 545–57)[1] has published an account of the variation in a large number of specimens of *Volutospina spinosa* from the Calcaire Grossier of Grignon. In his study of that group he emphasized the variation in the ontogeny of the individual, and suggested the importance of such studies in relation to the more philosophical aspects of biology and in relation to the application of ontogenetic evidence to the problem of classification. The group studied by Mr. Stuart was one in which the latitude of variation in any character was particularly small.

The present paper deals with variation in *Batillaria pleurotomoides* (Lam.), and the variation in shell form as well as in ontogenetic features is discussed. This series was chosen by way of contrast with *Volutospina spinosa*, because the latitude of variation in each of the characters is so considerable that previous writers have established several species for forms which are here regarded as members of the same species group.

The species was referred by Lamarck (1804, p. 348) to the genus *Cerithium*, and retained in that genus by Deshayes (1824, p. 344) and Bronn (1848, p. 272). In 1889 (p. 82) Cossmann placed the species with the genus *Lampania* of Grey, but later (1906, p. 132) noted that that genus should be replaced by the earlier *Batillaria* (Benson, 1842, p. 488). It has also been referred to the genus *Potamides* (Zittel, 1913, p. 550), the distinction of which from *Cerithium* has frequently led to confusion. More recently Charpiat (1923, p. 191) has transferred the species to his newly re-constituted genus

---

[1] The dates refer to the list of works given at the end of the paper.

Cerithium, but it appears to the writer to be more convenient to refer to it here as *Batillaria pleurotomoides*.

The material studied consists of specimens of *Batillaria pleurotomoides* (Lamarck) in the Reader Collection at the University College of Swansea, which were collected from the Bartonian of Mortefontaine near Paris. Some 240 specimens were sufficiently complete to afford information for the present purposes and a record of the ontogeny of all these specimens was made. The species is typical of Benson's species, and includes varieties similar to those named Var. α, Var. β, Var. γ, and Var. δ by Deshayes (1824, p. 344).

The writer wishes to acknowledge his indebtedness to Dr. F. A. Bather, F.R.S., for facilities and permission to examine specimens and for access to literature at the British Museum (Natural History), also to Mr. L. R. Cox, M.A., for help in identification and comparison with specimens at that Museum, and to Dr. T. N. George, M.Sc., St. John's College, Cambridge, for information. The writer also wishes to thank Dr. A. E. Trueman for continued advice, guidance, and encouragement throughout.

ONTOGENY OF A TYPICAL SPECIMEN.

In many of the specimens the protoconch is not preserved and in those specimens which show the protoconch the apex is so poorly preserved that it is difficult to distinguish. It is probable, however, that the protoconch consists of at least two smooth whorls. The first whorl after the protoconch is slightly flattened and ornamented by a number of fine spiral threads, three of which are usually more prominent than the rest. These spirals are later crossed by ribs usually on about the fifth whorl. Where the ribs cross the spirals there is developed a prominence in the ornamentation giving a node or tubercle, the tubercles becoming more prominent on successive whorls. Thus we have an ornamentation consisting in appearance of three rows of tubercles. Usually two of these rows persist while the row nearest to the anterior suture becomes feebler and disappears leaving only two rows.

On later whorls, usually on about the twelfth, another row, again the anterior one, becomes weaker and disappears, leaving the whorl ornamented with one row of tubercles only, this row being the one nearest to the posterior suture which has persisted from the earlier whorls. In a few cases this row also disappears leaving the last whorl showing only growth lines.

There also appears to be a slight progressive change in the whorl shape from a flat whorl to an evenly convex whorl, but the exact whorl shape is difficult to decide owing to the prominence of the ornamentation.

The ontogeny of a typical specimen of *B. pleurotomoides* may be summarized as follows :—

	Ornamentation.	*Whorl shape.*
Protoconch	Consists of at least two smooth whorls.	Flat whorl, suture well defined.
3rd whorl 4th whorl	A number of spirals, three usually prominent.	Slight increase in convexity.
5th whorl	Ribs added to spirals, giving in effect three rows of tubercles.	
6th to 9th whorl.	Tubercles become more prominent, except anterior row which gradually weakens.	
10th whorl	Anterior row of tubercles disappears, leaving two rows only.	
11th whorl 12th whorl	Weakening of second row.	
13th whorl	Disappearance of second row leaving one row.	
14th whorl	Weakening of third row.	

Chief Types of Variation.

Variation in Persistence of Ornamentation.

1. *Spirals.*

The apex of the shell is usually poorly preserved but the protoconch appears to be immediately followed by a whorl showing spiral ornamentation. The spirals are usually three in number, but in cases of very good preservation finer threads can be seen between. These spirals form the only ornamentation until the axial ribs are acquired. Fig. 1 shows the curve representing the frequency of the number of whorls on which spirals are present without axials. This curve of necessity is similar in form to a curve which shows the frequency of the number of the whorl upon which ribs first appear.

An inspection of the curve shows that in the largest number of specimens the stage with spirals alone persists over one whorl, but the mean for the whole of the specimens examined is 2·13 whorls. This difference arises from the fact that very little variation from the mode is possible in the direction of the smaller number of whorls with spirals, while there is a considerable range of variation in the other direction, occasional specimens retaining this stage of spirals without axials for a total of seven whorls. It will thus be noted that the variation in the number of whorls showing this type of ornamentation is considerable, ranging from specimens with the spiral stage omitted, to specimens which have in their ontogeny seven whorls with spirals alone. It is seen that the maximum number of shells have the spiral stage early in their ontogeny, while nine specimens have accelerated their ornamentation to such an extent as to cut out this stage entirely, the whorl following the protoconch showing spirals with ribs.

2. *Three Rows of Tubercles.*

The next stage in the ornamentation consists of spirals crossed by axials or ribs, giving in effect three rows of tubercles. The graph

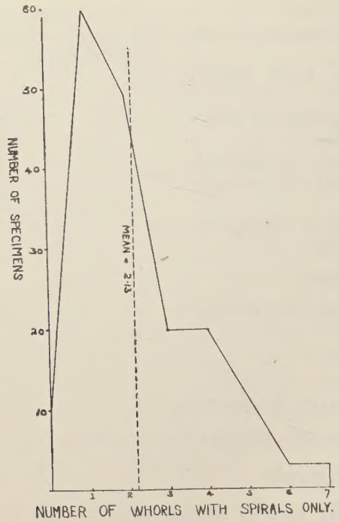

FIG. 1.

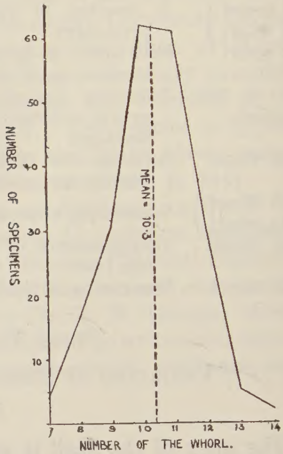

FIG. 2.

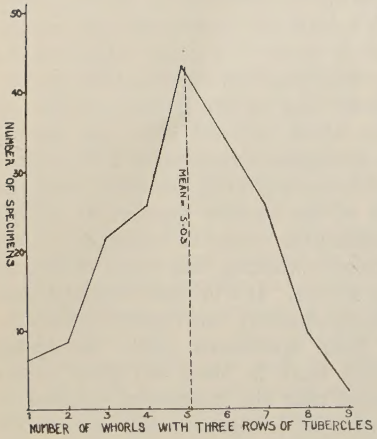

FIG. 3.

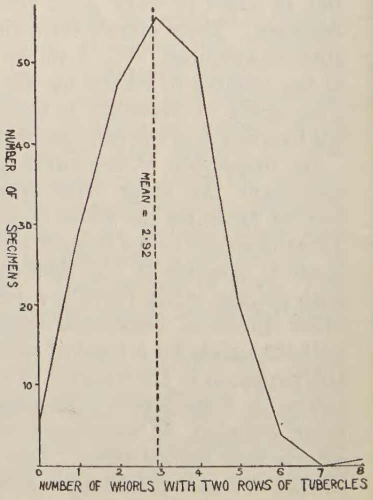

FIG. 4.

FIGS. 1–4.—Graphs showing the variation in the ornamentation of *Batillaria pleurotomoides* from the Calcaire Grossier, Paris.

1.—Variation in the number of whorls with spirals only.
2.—Variation in the number of the whorl in which the lowest row of tubercles disappears.
3.—Variation in the number of whorls on which three rows of tubercles persist.
4.—Variation in the number of whorls on which two rows of tubercles persist.

showing the stage at which ribs first appear is necessarily comparable with Fig. 1. Fig. 2 shows the variation in the number of the whorl on which the lowest row of tubercles disappears leaving two rows of tubercles only. Fig. 3 shows the variation in the number of whorls on which three rows of tubercles persist.

The mean number of whorls for which three rows of tubercles persist is 5·03. The mean for the number of the whorl upon which ribs first appear is 5·13 and the mean for the number of the whorl on which the lowest row of tubercles disappears is 10·3. Subtracting these, we have the mean number of whorls on which three rows persist, that is 5·17, which approximates fairly closely to the value of 5·03 given by direct measurement.

These curves show that there is considerable variation both in the stage at which this type of ornamentation appears, and in its persistence in the ontogeny of each specimen. In some specimens three tubercles are present on the third whorl, but in the majority this stage is not reached until the fourth, while in some it is retarded until the tenth whorl. The persistence of this type of ornamentation varies from one whorl to nine whorls. Six specimens passed beyond the three-tubercle stage quickly, in one whorl. The maximum number have this stage over five whorls, while in two extreme cases this stage persists to such an extent as to occupy nine whorls. In none of the specimens examined was this stage so prolonged as to continue to the latest whorls, and it was in every case succeeded by a stage with two rows of tubercles. Also seeing that each ontogeny commenced with either a spiral stage followed by ribs or a stage with spirals and ribs together, the stage with three rows of tubercles has not, in any specimen examined, been cut out entirely from the ontogeny by the acceleration of the ornamentation.

3. *Two Rows of Tubercles.*

The curve in Fig. 2 shows the variation in the number of the whorl on which the third row of tubercles disappears and Fig. 5 shows the variation in the number of the whorl on which the second row of tubercles disappears. The variation in the persistence of this type of ornamentation (that is, two rows of tubercles) for each specimen is shown in Fig. 4. The curves show that in the maximum number of specimens the stage with two rows of tubercles commences on the tenth whorl, but the mean value is at 10·3. In some specimens this stage comes on as early as the seventh whorl, while in two specimens the ornamentation is retarded at this stage so that the third row of tubercles does not disappear until the fourteenth whorl.

Fig. 4 shows the persistence of the two rows of tubercles in the ontogeny. The maximum number of specimens retain this stage for three whorls ; the curve is almost symmetrical, the mean being 2·92.

In four cases this stage persists for six whorls, but one extreme specimen has this stage for eight whorls, while in twenty-six of the specimens examined the two rows of tubercles were retained to the last whorl. Owing to the retardation of the stage with three rows of tubercles and the acceleration of the disappearance of the second row of tubercles, in six of the specimens examined the stage with two rows of tubercles has been cut out entirely, the ornamentation passing in development from three rows of tubercles to one row.

4. *One Row of Tubercles.*

The curve in Fig. 5 shows the variation in the number of the whorl on which the second row of tubercles disappears, leaving one row only. Considerable variation is again shown in this stage of the ornamentation. In the maximum number of specimens (54) the second row of tubercles disappears on the fourteenth whorl, while fifty-three specimens show this stage on the thirteenth whorl, so that in approximately 53 per cent of the specimens examined, the stage of one row of tubercles is assumed on the thirteenth or fourteenth whorl.

The mean value for all specimens examined is 12·9. In one specimen the ornamentation is accelerated to such an extent that the second row of tubercles disappeared on the eighth whorl. This was an exceptional specimen in which the axial ornamentation was very feeble. In two specimens examined the second row of tubercles disappeared on the ninth whorl. One of these also had feeble axials but the other had accelerated this state of the ornamentation so as to cut out the stage with two rows of tubercles, the ornamentation going from the stage with three rows to the stage with one row.

In another extreme case the ornamentation was retarded so that the second row of tubercles did not disappear until the sixteenth whorl. This specimen was the longest specimen examined (3·1 cm.) and consisted of seventeen whorls. The other stages of the ornamentation are normal in this individual, but the stage with two rows of tubercles persists for eight whorls.

A curve was plotted to show the variation in the number of whorls on which one row of tubercles persists. It must be borne in mind that this graph is not strictly to be compared with that showing the number of whorls on which two rows of tubercles persist, for in almost every shell the stage with one row of tubercles is retained to the end of the last whorl and no stage without tubercles is ordinarily attained.

On the maximum number, as shown by the curve, this stage persists for one whorl only, while in thirty-five specimens the ornamentation is retarded to such an extent that the stage with two rows of tubercles persists to the last whorl, the stage with one row not appearing in the ontogeny of these individuals. The curve also shows that in a few cases this stage of the ornamentation has been accelerated, and persists for five whorls in three specimens, and for six whorls in two specimens.

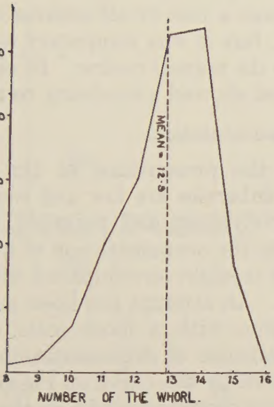

Fig. 5.

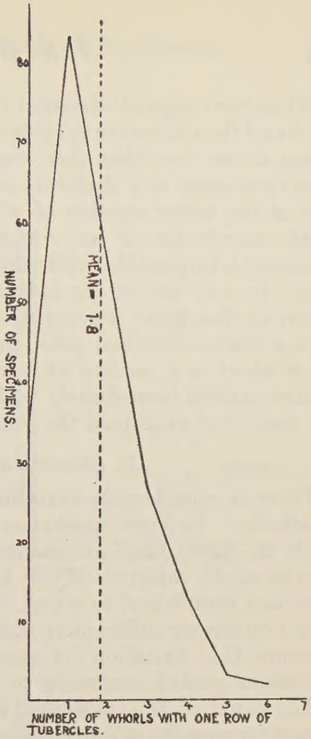

Fig. 6.

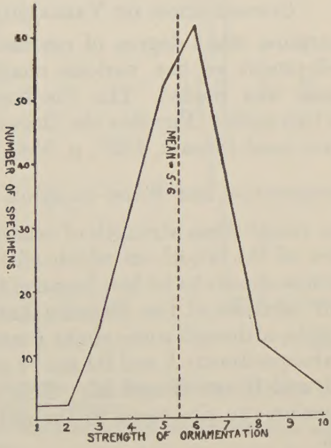

Fig. 7.

Figs.

5–7.—Graphs showing variation in the ornamentation of *Batillaria pleurotomoides.*

5.—Variation in the number of the whorl on which the second row of tubercles disappears, leaving one row only.

6.—Variation in the number of whorls with one row of tubercles.

7.—Variation in the strength of ornamentation.

While the range of variation extends from 0 to 6 whorls, the mean is 1·8 and the maximum value is at 1. The curve is thus asymmetrical, owing to the fact that this stage of the ornamentation comes late in the ontogeny and therefore much variation from the mean on the side of the larger number of whorls is impossible; in other words much retardation in an ornamentation which comes late in the ontogeny is impossible, while there is always a possibility of acceleration. In only one of the individuals examined did the last row of tubercles disappear, leaving the whorl without tubercles.

In a few exceptional cases there was a loss of all ornamentation for a whorl or a portion of a whorl, but it was temporary and the ornamentation immediately took up its normal course. In eight of the specimens examined the last whorl showed a tendency to uncoil.

5. *Strength of Ornamentation.*

There is considerable variation in the prominence of the ornamentation. In some specimens the tubercles are low and rounded, while in others they are comparatively long and pointed. There is some slight variation of this kind in the ornamentation of a single specimen from whorl to whorl, but it is slight as compared with the variation among different specimens. An attempt has been made to measure this variation by comparison with a fixed scale of ten specimens graded according to prominence of ornamentation.

The variation thus measured is shown by the curve on Fig. 7. The maximum number of individuals have a prominence of 6 on the scale, while the mean is at 5·6.

Correlation of Variations.

In order to determine what degree of correlation, if any, exists between the development of the various characters, a series of "scatter" diagrams was made. The Coefficient of Correlation was determined in two cases. For this the Bravais-Pearson Product Moment formula was used (Stuart, 1927, p. 554).[1]

1. *Strength of Ornamentation and Whorl on which Ribs First Appear.*

Fig. 8 shows the result when strength of ornamentation is plotted against the number of the whorl on which ribs first appear. The degree of correlation is shown to be low because the grouping results in each of the four sections of the diagram having a considerable number of individuals, although some slight correlation is suggested by the fact that in the quadrants A and B1 are 74 and 36 points respectively, while in A1 and B are 47 and 23. This appears to indicate broadly that the earlier the ribs come in the ontogeny the stronger the ornamentation.

Further it is seen that when the ribs come on the third whorl the strength of the ornamentation is always five or more, but when the ribs come late in the ontogeny, that is on the 8th, 9th or 10th

---

[1] See also H. M. Vernon, 1903, pp. 25–31.

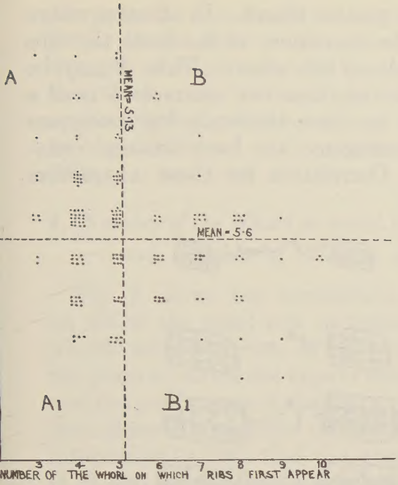

Fig. 8.

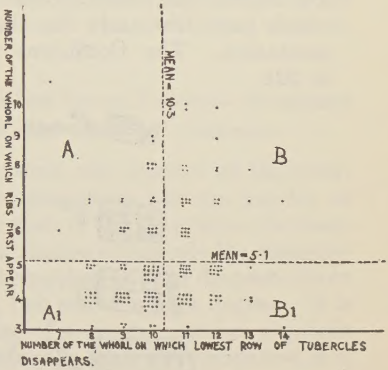

Fig. 9.

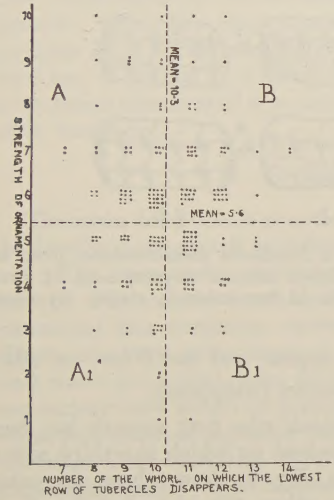

Fig. 10.

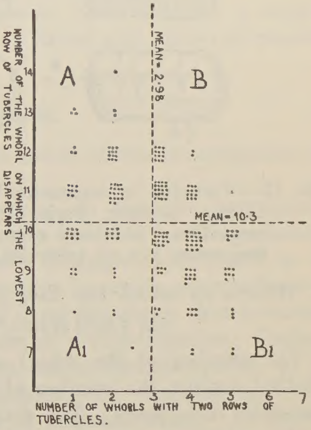

Fig. 11.

Figs.

8–11.—Scatter diagrams showing the relation between types of ornamentation of *Batillaria pleurotomoides*.

8.—Relation between the strength of ornamentation and the whorl on which ribs first appear.

9.—Relation between the first whorl with ribs and the first whorl with two rows of tubercles.

10.—Relation between strength of ornamentation and the first whorl with two rows of tubercles.

11.—Relation between the number of the whorl on which the lowest row of tubercles disappears and the number of whorls with two rows of tubercles.

whorl, the ornamentation is never greater than 6. In all cases where the ornamentation has reached the maximum of the scale the ribs have been acquired on the 3rd, 4th or 5th whorl. Thus it may be said that while the correlation between these two characters is of a low degree, yet there appears to be some tendency for specimens which have ribs early in the ontogeny to have strong ornamentation. The Coefficient of Correlation for these characters is ·201.

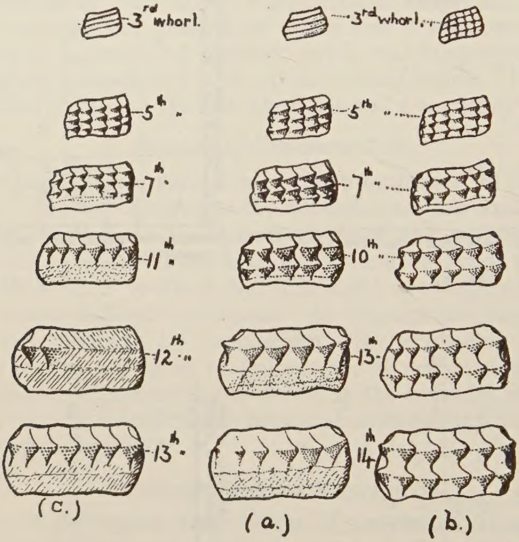

Fig. 12.—Variation in ornamentation of *Batillaria pleurotomoides* from the Calcaire Grossier, Paris. (*a*) Shows normal development of ornamentation; (*b*) shows retardation of two-tubercle stage; (*c*) shows temporary loss of tubercles.

2. *Whorls on which the Ribs first appear and the Whorl on which the Third Row of Tubercles Disappears.*

The number of the whorl on which ribs first appear has been plotted against the number of the whorl on which the third row of tubercles disappears. The diagram, Fig. 9, shows these characters to be entirely independent of each other, the lower quadrants A1 and B1 are numerically greater than B and A. The stage at which ribs come into the ontogeny appears to bear scarcely any relation to the stage at which the third row of tubercles disappears.

3. *Strength of Ornamentation and the Whorl on which the Third Row of Tubercles Disappears.*

The next two characters plotted were strength of ornamentation and the number of the whorl in which the third row of tubercles disappears. The result is shown in Fig. 10. Here the grouping of points in the four sections is surprisingly even, showing that the strength of ornamentation bears little relation to the stage at which the third row of tubercles disappears, both characters being apparently independent of one another. This is further indicated by the Coefficient of Correlation for these two characters, which is ·008.

4. *Number of the Whorl on which the Third Row of Tubercles Disappears and number of Whorls with two Rows of Tubercles.*

Fig. 2 shows the correlation between the number of the whorl on which the third row of tubercles disappears and the number of whorls with two rows of tubercles, that is the correlation between the point at which the type of ornamentation comes into the ontogeny and the persistence of that type in the ontogeny. The diagram shows that there is a definite correlation, but not of a high degree. It is interesting to note that the grouping of a greater number of points in B and B1 than in A and A1 indicates that the correlation is a negative one. This means that the earlier the two-tubercle stage of the ornamentation comes into the ontogeny the longer does it persist; when the stage comes in late in the ontogeny it only persists for a small number of whorls. However, the considerable number of points in A1 and B1 shows that although a negative correlation is indicated it is extremely broad and allows of considerable variation.

CONCLUSIONS.

The main conclusions reached as a result of this investigation may be briefly summarized as follows :—

1. The specimens examined appear to form a homogeneous group. This may be concluded from the fact that for every character examined the variation curves show a single mode (1903, p. 41). There is a very wide range of variation in nearly every character, and some specimens differ so much from the mean that considered separately they would be perhaps termed distinct species; Deshayes regarded them as separate varieties, while Charpiat (1923, p. 192) describes four varieties of this species, the varieties apparently depending partly upon differences of ornamentation. It appears, however, that they can be considered as variants within a widely varying group.

In a similar group (*Potamidopsis tricarinata* Lam.) Miss Elvira Wood (1910, pp. 66–9) named a large number of mutations, whose relations appear to be comparable with the variations discussed here, since they " occur at the same horizon and locality as the type, and, as might be expected, transitional forms exist between them all " (1910, p. 67).

Whether separate names are desirable to indicate certain member of such a group must depend on the nature of the variations met with both at other localities and at other horizons. For instance Mr. J. H. Davies and Dr. A. E. Trueman (1927, p. 218–19) propose to use distinct names for groups of individuals which are admittedly variants within a species-group, when definition of the form is desirable for stratigraphical purposes. Dr. F. A. Bather (1928, pp. 51–2) has recently made reference to such a species-group and has pointed out that in such groups the holotype is not necessarily the norm.

This appears to be the case in *Potamidopsis tricarinata* just referred to, since Miss Wood (1910, p. 68) has pointed out that one of her mutations is more common than the typical forms of the species. Unfortunately it has not proved possible to examine the holotype of *Batillaria pleurotomoides* and thus its position in the group cannot be indicated.

2. Correlation between the various characters is almost entirely absent. Some slight degree of correlation is exhibited between the whorl upon which the third row of tubercles disappears and the number of whorls with two rows of tubercles, but on the whole such characters as the number of the whorl on which ribs appear and the whorl upon which the third row of tubercles disappears, show no apparent correlation. This relative independence in biocharacters has been shown to be of frequent occurrence and of great importance in the evolution of invertebrates (Swinnerton, 1923, p. 390), and it is interesting to find that it can be detected in ontogeny as well as in adult characters.

3. The ornamentation varies in :—

(*a*) Strength.

(*b*) Stage at which certain characters come into the ontogeny.

(*c*) Stage for which the characters persist in the ontogeny.

In each of these characters there is a remarkably wide variation. This may be contrasted with Mr. Alan Stuart's study of *Volutospina spinosa* in which the latitude of variation was particularly small. It is notable that in *Batillaria pleurotomoides*, which shows wide variation in adult characters, a similarly wide variation in ontogeny is exhibited. The present study emphasizes the need for caution in basing too hasty conclusions as to phylogeny on the interpretation of the ontogeny of a single specimen of a variable group.

4. The tendency in the evolution of the ornamentation appears to be towards a non-tuberculate form, but it has not yet been possible to study a sufficient number of members of this plexus at other horizons to make adequate comparisons of the variation at later stages.

LIST OF WORKS REFERRED TO.

Bather, F. A. (1928).—" The Shifting Diagnosis," *Palaeobiologica*, I Bd.

Bronn, H. G. (1848).—*Index Palaeontologicus.*

Benson, W. H. (1842).—" General features of Chusan, with remarks on the fauna and flora of that island," *Ann. and Mag. Nat. Hist.*, p. 262, etc.

Cossmann, A. E. M. (1889).—" Catalogue illustré des coquilles fossiles de l'Eocene de Paris," *Ext. Soc. Roy. Malac. Belg.*, t. xxiv.

Cossmann, A E. M. (1906).—*Essais de Paléochonchologie comparée*, vol. vii.

Charpiat, R. (1923).—" Recherches sur l'Evolution des Ceritidae Tertiaires du Bassin de Paris, etc.," *Bull. Soc. Seine et Oise*, ser. ii, t. iv, pp. 1–297.

Deshayes, G. P. (1824).—*Description des coquilles fossiles des environs de Paris.*

Davies, J. H. and Trueman, A. E. (1927).—" A Revision of the Non-Marine Lamellibranchs of the Coal Measures, etc.," *Quart. Journ. Geol. Soc.*, vol. lxxxiii, pp. 210–59.

Lamarck (1804).—" Suite des Mémoires sur les fossiles des Environs de Paris," *Ann. du Mus. Nat. d'Hist. Nat. de Paris*, t. iii.

Swinnerton, H. H. (1923).—*Outlines of Palaeontology.*

Stuart, A. (1927).—" Ontogenetic and other Variation in *Volutospina spinosa*," *Geol. Mag.*, vol. lxiv, pp. 545–57.

Vernon, H. M. (1903).—*Variation in Animals and Plants.*

Wood, E. (1910).—" The Phylogeny of Certain Cerithiidae," *Ann. N.Y. Acad. Sci.*, vol. xx, p. 1.

Zittel, C. von (1913).—*Text-book of Palaeontology*, edited C. R. Eastman, vol. i, 2nd ed.

Metamorphism in the Upper Devonian of N. Cornwall.

By F. Coles Phillips, M.A., Ph.D., F.G.S., Fellow of Corpus Christi College, Cambridge.

I. Introduction and Previous Literature.
II. Field-Relations.
  The granite aureole.
III. Petrography.
  Macroscopic details.
  Microscopic details.
    Development of chloritoid.
    Chlorite-mica phyllites.
    Volcanic series.
    Intrusive " greenstones ".
  Superposed thermal metamorphism.
IV. Discussion and Comparison.
V. Summary.
VI. Acknowledgements.

I. Introduction and Previous Literature.

THE rocks whose condition of metamorphism forms the subject of this discussion lie immediately to the south of the Devonian-Carboniferous boundary which runs across Cornwall in a direction roughly W.N.W.—E.S.E., from Boscastle on the west coast towards Tavistock in Devonshire and the granitic intrusion of Dartmoor. For part of this course they flank the companion intrusion of the Bodmin Moor granite. The area is not easy to work geologically as good natural exposures are rare except on the coast in the west ; even many of the artificial exposures inland accessible to earlier workers are now no longer available. The majority of these were small openings worked for road-stone, but with increased facilities for transport this industry has become centralized, and the small quarries overgrown or filled up. Material from the surface of pasture land is seldom fresh, and one is driven largely to depend on small field-pits and temporary excavations.

Previous contributions to the geology of the area are few, and the majority of these deal with the better-exposed western portion. A few of the earlier writings are noted in the list of references appended. The occurrence of chloritoid was first described by Hutchings (1889, 2), and in the same year he also wrote on the altered igneous rocks of the district. Parkinson (1903) added some detailed descriptions, but the essential structural features of the overthrust district of Tintagel were first elucidated by Mr. Dewey (1909), this paper being concluded by brief notes on the nature of the metamorphism. The Survey Memoirs on sheets 335 with 336, and sheet 337 (New Series), were published in 1910 and 1911 respectively, and contain the only printed descriptions of the phyllites of the eastern part. The area immediately around Boscastle, Tintagel, and Davidstow, falls into sheet 322 to the north, of which no map or memoir has been published, although most of it has been mapped by the Survey. Dr. Tilley has recently published a further description of the chloritoid phyllites of Tintagel (1925), affirming that they are typical products of dynamic metamorphism.

II. FIELD RELATIONS.

The major structural feature of the district is the Davidstow anticline and its associated smaller folds. The axis runs N.W. and S.E. and pitches to the N.W., away from the Bodmin Moor granite which is intruded on the axis of the fold. On the N.E. flank, higher beds are reached in succession on passing northwards, dipping towards the overlying Culm Measures of the central Devon syncline. On the west of the Moor the beds strike around the nose of the syncline and S.W. of Camelford dip approximately to the S.W. The stratigraphical succession by which Mr. Dewey was enabled to elucidate the overthrust structure of the Tintagel district is as follows:—

Tredorn phyllites.
Trambley Cove beds.
Volcanic series.
Barras Nose beds.
Woolgarden phyllites; Hallwell Cottage beds.
Delabole slates; Slaughterbridge beds.

The further south-east one passes, the more difficult does elucidation of the structure become. Between Stoke Climsland and Tavistock fossiliferous strata are rare, and overthrusting becomes more and more prevalent, in addition to minor disturbances due to the small granite intrusions of Kit Hill and Gunnislake, and the major disturbance due to the Dartmoor mass.

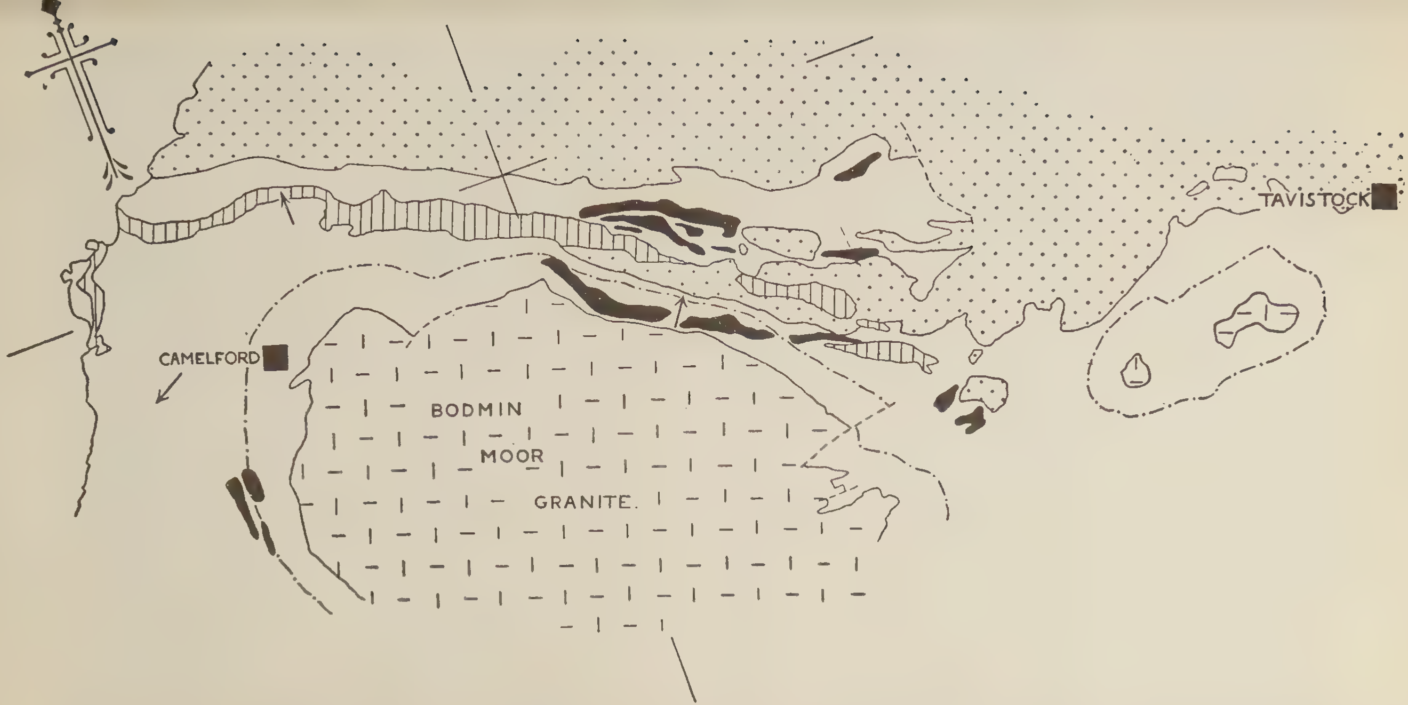

FIG. 1.—Geological sketch-map to show the relationships of the Upper Devonian of North Cornwall. Stippled, overlying Carboniferous; lined, volcanic series; black, intrusive greenstones; white, Upper Devonian sediments. The chain line around the granitic intrusions marks the outer limit of spotting in pelitic rocks. The positions of the 1 in. colour-map sheets of the geological survey, to which reference should be made for details of localities, are indicated by the north-south and east-west broken lines. Scale approximately 4 miles to 1 inch.

Evidence of powerful earth-movements throughout the Devonian slates[1] of North Cornwall is not far to seek. Commencing with the Lower Devonian of sheet 335, there is noticeable everywhere a lenticular or thrust-plane structure developed by powerful regional movement. On the railway between Dunmere and Boscarne, exposures are good, and again at Grogley Halt grits are seen violently contorted and fractured, the fissures being filled with vein-quartz.

The grey slates and thin limestones of the Middle Devonian show similar features. On the coast near Bedruthan Steps the beds are thrown into enormous folds broken across by faults and thrusts. In quarry sections inland there is often developed a kind of rodding structure due to movement parallel to the axis of puckering.

In the Upper Devonian, the division with which this discussion is specially concerned, the disturbance is very great; whence the original difficulty in establishing the succession, no undisturbed type-section being available. The general disposition of the beds in a pitching anticline has been outlined above; to the south subsidiary folds are developed, as in the Trevena Valley, and further west in the area around Tintagel folding has passed into overthrusting. Dynamic disturbances are particularly prominent around the western margin of the granite, where the movement has passed beyond folding and cleaving into intense shearing. The beds are often torn up into lenticles, and silica has segregated into lenticles of quartz. The movements were anterior to the intrusion of the granite, for the quartz segregations become recrystallized where they approach the intrusion. The typical Delabole slates are well-cleaved sericite-phyllites, thoroughly altered and in no sense a clay-slate. They display nowhere the strain-slip cleavage so common in the grey slates further south. Laterally the Delabole slates merge insensibly into the Slaughterbridge phyllites, highly micaceous schistose rocks. Near Camelford the rocks can only be described as mica-schists. In the calc-flintas of the same area, finely divided matter is often so arranged as to display clearly the intense contortion suffered by the rock anterior to its thermal metamorphism; and intrusive sills are folded, overthrust, disrupted and drawn out into thin films in such a manner as almost to disguise the original relationships.

The eastern portion of the area, included in sheet 337, is equally characterized by violent overthrusting, accompanied by shearing and brecciation, so that the original disposition of the unfossiliferous strata cannot be deciphered. Finally, throughout the area, the Carboniferous grits and sandstones have been thrust over the

---

[1] This paper seeks to provide a modified interpretation of the conditions of metamorphism based on detailed petrographical study, rather than to put forward any fundamentally new field discoveries. Many of the facts in the next few paragraphs are quoted word for word from scattered sentences in the official survey memoirs: it has not been deemed necessary to give individual page-references for each item of the information thus assembled.

Devonian, so that they now rest on various horizons, and probably hide in places the uppermost Devonian strata completely.

The intrusive greenstones have likewise suffered; unsheared cores are found lying in more schistose rock, and the original components have often broken down to yield a milled structure. The isolated outcrops of the masses around Michaelstow are apparently the result of disruption of an originally continuous mass.

The Granite Aureole.

In the area under discussion the Upper Devonian sediments pass within the influence of the Bodmin Moor granite and of the Kit Hill and Gunnislake intrusions. The joint aureole of uniform width around these latter intrusions calls for no further comment. The extent and position of the aureole due to the larger intrusion is more vital to the problems in hand. Earlier writers tended with more or less definiteness to refer many of the mineralogical changes in the slates to the contact-effect of the granite. Near the surface outcrop on Bodmin Moor, the aureole was widened to include many of the phyllites. Further away the presence was postulated of an intrusion beneath the surface and not yet exposed by denudation. The memoir states (Sheets 335 and 336, p. 63) :—

> Along the southern and much of the western margin of the intrusion the alteration of the killas can be traced to a distance of about three-quarters of a mile from the granite ; to the north of the fault at the Devil's Jump the aureole rapidly increases in breadth as Camelford is approached, being fully a mile and a half wide at Lanteglos. This increased breadth is maintained all along the northern edge . . .

On the one-inch colour-printed map the extension, particularly north of Camelford, seems to have been carried even further than the descriptions in the memoir would warrant. It is difficult to establish any practical method by which the outer limit of thermal action can be accurately delimited. Where the rocks are calcareous, alteration naturally takes place to a greater distance from the granite than that to which any change can be traced in a slate. If attention be confined to non-calcareous rocks, the first change easily detected is a slight spotting. Even the use of this criterion is open to the objection that the spots in different cases are differently produced, and it is of course also true that

> " outside the zone of spotting we can often recognize . . . an outer aureole [of hardening and bleaching] which graduates imperceptibly into the unaltered rocks beyond " (Memoir on sheet 337, p. 75).

This paper is concerned, however, with extensive mineralogical reconstruction in the phyllites; the aureole of the granite on the accompanying map has been laid down as the outer limit of spotting in normal pelitic sediments, and it would seem a reasonably safe assumption that notable mineralogical changes in pelites well outside this limit are not " contact-changes " due directly to the thermal effects of the intrusion.

Commencing on the map on the eastern margin of the granite, the aureole lies at a distance of about $\frac{3}{4}$ mile. Turning north-westwards, north of North Hill, and from here towards Knighton, it is even less than the normal distance from the outcrop of the intrusion. Chloritoid-phyllites from a field-pit south-west of the road from Trebartha Barton to Trevadlock reveal no traces of spotting; the limit must pass approximately through Knighton for slices from here are practically unspotted. Good exposures again occur in and around the Penpont Water above and below Altarnun, and enable the limit to be laid down fairly precisely, just north-east of the village; while specimens from the river-bed south-west of the village show incipient development of biotite, a locality 500 yards N.N.E. of the village yields unspotted chloritoid-phyllites comparable in thin slices with those from farther south-east. The limit can be traced off this sheet by examples from near Trekennick and the stream north-west of Tresmeak, through Hurden. The line then runs near Higher Basil and south of New-house, where the phyllites are unspotted. Across Davidstow Moor exposures are infrequent, but faint traces of spotting are visible in material from Grigg's Down. The aureole then turns gradually south-west past Trenuth and Trefrew. Phyllites from a small excavation near the road-bridge at Slaughterbridge are unspotted as stated in the memoir, in spite of the location of the signs on the one-inch map. Calcareous beds come in south of Lanteglos, whence the aureole can be traced at a distance of rather less than $\frac{3}{4}$ mile through Michaelstow and off the map towards Wenfordbridge. (The limit as laid down on the accompanying map is consistent with over 50 slices examined by the author.)

Outside this limit no evidence of recognizable thermal spotting has been produced, either in the west around Tintagel, or in the east outside the Kit Hill-Gunnislake aureole. Only occasionally is there a reminder that the presence of the intrusion is not to be too hastily ruled out of account, as for example the schorl-veins noted by Mr. Dewey (1909, p. 278), at Trewethet Gut, 5 miles from the granite margin. (The wide-spread distribution of microscopic tourmaline-needles in the phyllites is a phenomenon of another order; compare, for instance, its presence in the schists of the Scottish Highlands.)

III. PETROGRAPHY.

Macroscopic Details.

The Delabole Slates have been repeatedly described owing to their extensive economic exploitation. The grey-blue roofing-slate, compact and highly fissile, grades into a much less fissile green rock. Around Slaughterbridge the beds are more highly micaceous true phyllites, whose microscopic details will be discussed below.

The Woolgarden Phyllites (Hallwell Cottage Beds of Parkinson) form a variable series of banded sediments of alternating gritty and argillaceous material. The mineral development on metamorphism is of course dependent on the composition of each particular layer, but a frequent feature is the presence of porphyroblasts of a green mineral visible to the naked eye. Occasionally this mineral is chloritoid, and the horizon has been mapped as " ottrelite-schist " on the Camelford sheet and as " chloritoid-schist " on the Tavistock sheet. Much of the material is not true chloritoid, and its development is not confined to the Woolgarden phyllites (Tilley, 1925, p. 316). The survey's designation was apparently chosen as a convenient group-name, and would not be adhered to in a revised map.

The Barras Nose Beds and the Trambley Cove Beds, below and above the Volcanic Series respectively, are fine-grained highly quartzose grits. They are usually black in hand-specimens (" blue-black slates ") and thus ot value in mapping. Their simple constitution results in little effect on metamorphism beyond brecciation and eventual recrystallization and we are scarcely concerned with them further. Their designation as " quartz-schists " seems scarcely desirable.

The Volcanic Series are highly sheared lavas now usually found as dark green or purple schists. They were originally spilitic and remains of vesicular structure are often visible.

The Tredorn Phyllites, grey mica-phyllites with poor cleavage, mark a return to the normal type of sedimentation.

Microscopic Details.

Development of chloritoid.

Chloritoid-bearing phyllites are found throughout the area, from Tintagel in the west, where Hutchings first recorded " ottrelite ", at intervals along the northern margin of Bodmin Moor, and across the Tamar into Devonshire. Dr. Tilley has described and figured examples from near Tintagel, and those of other parts of the area are similar. The rocks are all quartz-bearing chloritoid-chlorite-phyllites with variable amounts of colourless mica. The chloritoid is porphyroblastic, and may be positively separated by the combination of its optical properties—relatively high refractive index, medium double refraction and high optic axial angle—from other greenish minerals occurring in the slices. Usually, also, the characteristic greenish-blue tint of one axial colour is helpful, but chloritoid from near Morwellham is almost colourless and non-pleochroic even in rather thick slices. Previous writers have pointed out the confusion between true chloritoid and members of the chlorite group, but it seems certain that other greenish minerals, epidote and amphiboles, have been wrongly identified as chloritoid, for this latter has been described in association with minerals characteristic of a much more calcic assemblage.

With the two analyses quoted from the memoir (Anal. II and III) is placed an analysis representing the average of 51 shales. The chloritoid-phyllite shows the usual features of high alumina and ferrous oxide, together with low lime; the Delabole roofing-slate (Anal. III) shows similar characteristics, a fact which conforms with the observation that the development of chloritoid is not confined to the Woolgarden Phyllite horizon. With the incoming of a higher content of lime, the development of epidote may be expected, and higher alkalies cause the appearance of an alkaline plagioclase.

	I.	II.	III.
SiO_2 . .	60·15	55·44	57·76
TiO_2 . .	·76	1·20	·90
Al_2O_3 . .	16·45	22·23	20·62
Fe_2O_3 .	4·04	·92	1·85
FeO . .	2·90	6·83	6·08
MnO . .	tr.	·37	·15
CaO . .	1·41	·33	·40
BaO . .	·04	nt. fd.	—
MgO . .	2·32	3·55	2·41
Na_2O . .	1·01	1·58	1·46
K_2O . .	3·60	4·08	3·10
H_2O- .	·89	·08	5·03
H_2O+ .	3·82	3·17	
P_2O_5 . .	·15	·23	·16
CO_2 . .	1·46	nt. fd.	—
SO_3 . .	·58	$(Co,Ni)O$ ·06	FeS_2 ·11
C . .	·88		
	100·46	100·06	100·03

I. Average analysis of 51 palæozoic shales. *U.S.G.S. Bull.* 770, 1924, 552.
II. Sericite-chloritoid-phyllite, Trewassa. *Mem. Geol. Surv. Eng. and Wales*, Sheets 335 and 336, p. 33.
III. Delabole slate, Delabole quarry. Id.

Some details may be added of typical rocks from the eastern area, of which little description has been published. Very similar material is found at localities 500 yards north-north-east of Altarnun, in a field-pit near the bend in the road between Trevadlock and Trebartha Barton and in the Devonian inlier at Tredown (Memoir, Sheet 337, p. 80). They are fine-grained blue-grey phyllites with a glossy cleavage-surface, and frequently stained by ferruginous matter. Small chloritoid crystals are distinctly visible under a hand-lens. Under the microscope, porphyroblasts of acicular chloritoid average about ·25 mm. long, and lie at all angles to the foliation. By examination under a very low power, their capricious distribution even within the area of a single slice can be well appreciated; argillaceous lenticles rich in chloritoid needles are interspersed between lenticles rich in quartz or chlorite. The latter is present in the whole slice in subordinate amount to the cloritoid, and in the particular series under discussion usually forms elongated patches conforming with the general foliation rather than distinct porphyroblasts. The fine-grained ground-mass is composed mainly of colourless mica and grains of quartz, the former rarely in porphyroblasts set across the foliation but more usually contributing to a lepidoblastic arrangement. Some of the chloritoid needles show incipient alteration to chlorite, the usually-recorded change ; grains of the unaltered mineral stand out in good relief from the chlorite.

Other chloritoid-phyllites from east of the Tamar present very similar features, except that, as recorded by the Survey, there is a more marked tendency for a radiate grouping of some of the chloritoid to form sheaf-like bundles. In some of these rocks an eye-structure becomes pronounced, a very pale greenish pleochroic mica forming a lepidoblastic ground-mass displaced around the sheaves of chloritoid, the sheltered bays often occupied by quartz (cf. Grubenmann and Niggli, 1924, p. 466). The distribution of the chloritoid in relation to the schistosity is interesting, for while some forms the sheaves other needles can often be observed conforming with the direction of schistosity and eye-structure (Fig. 2*b*).

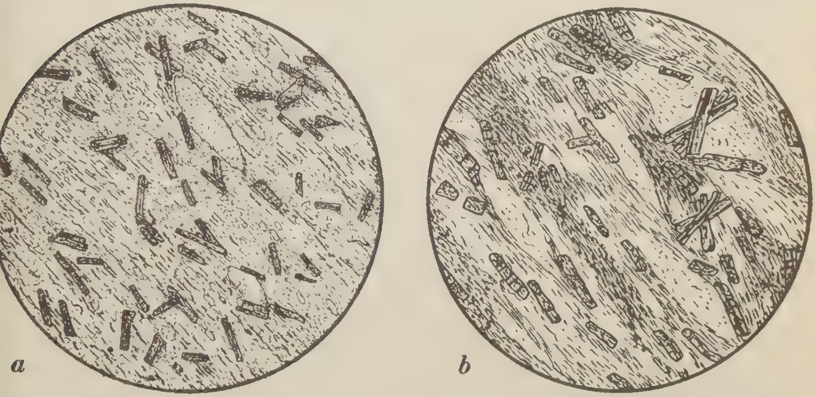

FIG. 2.—*a*. Fine-grained chloritoid-phyllite of the type found in many localities around the north of the granite of Bodmin Moor. *b*. Typical chloritoid-phyllite showing tendency to sheaf-like grouping of the porphyroblasts. Near Morwellham, Devonshire.

Chlorite-Mica-Phyllites and Mica-Phyllites.

Much more widespread than the phyllites with true chloritoid are those containing porphyroblastic chlorite and/or white mica. The optical properties of the chlorites, and their variation, have been exhaustively dealt with by earlier writers. Parkinson described the mineral in slices from Trewassa as clinochlore, and distinguished it from chloritoid (" ottrelite ") by its softness, lower specific gravity and lower refractive index. Mr. Dewey pointed out that there occurred abundantly a third greenish mineral, which did not agree optically with any described chlorite or chloritoid. Dr. Tilley considered the chlorite in specimens from Tintagel examined by him to accord more closely with penninite than with clinochlore.

Typical specimens of these chlorite-phyllites can be collected at many localities between Trewassa and Higher Basil. Being the metamorphosed equivalents of a finely-banded series, many varieties occur; south-west of Trevivian the more normal type passes into a schist composed almost entirely of chlorite. Usually there is a variable amount of colourless mica building a lepidoblastic ground-mass with occasional stumpy porphyroblasts. Chlorite occurs also in the ground-mass, and granular quartz. The iron-mineral is usually haematite, and rutile is abundant. In phyllites of the Slaughterbridge type the porphyroblastic chlorite is absent; only white mica occurs in this habit, and the ground-mass is frequently practically isotropic chloritic material.

The development of garnet in rocks of this group has been mentioned by other writers. The Delabole slates frequently contain minute garnets, and the Survey have figured and described a garnetiferous phyllite from Villaparks (Memoir, sheets 335 with 336, p. 32, and pl. IV, 5). Through the kindness of Dr. H. H. Thomas, I have been supplied with a small fragment of this rock. The crushed material gave a strong positive reaction for manganese. By means of heavy liquids, a small quantity of the garnet was obtained in a reasonably pure state, and a quantitative analysis for MnO gave a value corresponding to the presence of 12·5 per cent of the spessartite molecule. Since the separation was almost certainly incomplete, the actual spessartite content of the garnet must be even higher than this figure. The genetic significance of this fact will be considered below. Mention may be made here of indications of the presence of manganese in the Devonian sediments, though most of the ore formerly worked was associated with the Carboniferous. Cavities in the pillow-lavas are sometimes partially filled with wad (Memoir, sheets 335 with 336, p. 39), and the pyroxene of the calc-flintas is sometimes rhodonite (Memoir, sheet 337, p. 77).

Volcanic Series.

Previously to its dynamic metamorphism this series had already suffered extensive alteration of another type. Igneous activity of the Upper Devonian of Devon and Cornwall was essentially of the spilitic kind. Closely following upon their effusion the lavas were subjected to the action of juvenile magmatic solutions, with the introduction of considerable amounts of soda, and the conversion of the felspars to albite. This action is fixed as to age by the fact that the secondary products are affected by the earth-movements (Dewey and Flett, 1911, p. 205). The spilites thus present themselves chemically as a basic group very low in potash, but high in soda;

an exceedingly variable, but often very large, amount of calcite is present.

The main horizon of spilites with which we are here concerned runs from Bossiney Bay on the coast in the west, through St. Clether to near Coad's Green, and represents the phase of maximum volcanic activity in the Upper Devonian of the area. Other outcrops of lavas at different horizons occur ; in some instances, as the well-known Brent Tor rocks, the Survey have definitely shown that they belong to the Carboniferous ; in others, as at Lewannick, their age is doubtful though certainly they lie above the main horizon. Spilites of undoubted Upper Devonian age are highly schistose ; remains of original vesicular structure are betrayed by elongated calcite amygdales, but the exceptional preservation of pronounced pillow-structure is due to special circumstances. In the quarry at Tregunnon described by the Survey (Memoir, sheet 337, p. 49), a dolerite sill converted the adjacent spilites to a compact calc-flinta before the whole was subjected to dynamic metamorphism.

The most widespread type is a chlorite-albite-epidote-schist of the general nature of prasinite. Sometimes a pleochroic ferriferous epidote is developed throughout the slice ; often it is restricted to areas representing vesicles, where it is accompanied by calcite. Albite occurs in granular form, sometimes with subordinate amounts of quartz, and also in larger lenticular patches. Titanite and magnetite are common accessories, and calcite is almost universal. By decrease in amount of epidote these rocks pass into schists composed entirely of albite and chlorite. At Tintagel Haven porphyroblastic albite showing lamellar twinning occurs in a ground of chlorite, with accessory magnetite and calcite.

Some of these prasinites show incipient development of hornblende, in pale fibres intergrown with chlorite. These are transitional to types in which hornblende is extensively developed in large porphyroblasts, a feature hitherto ascribed to the thermal action of the granite. The amphibole is feebly pleochroic in shades of yellow-green, maximum absorption parallel to Y ; maximum extinction $Z \wedge c = 20°$, $2V$ greater than 80°, optic sign negative. Accompanying the extensive development of hornblende, the plagioclase becomes more calcic ; the optic sign changes, the refractive index rises towards 1·54 and if twinning is present there is a predominance of nearly straight extinction. A rock from 800 yards south-west of Trewinnow consists entirely of pale amphibole in a schistose matrix of yellow-green chlorite with accessory magnetite.

The incipient formation of biotite can be observed in some of these schists (Tredwen, Trevivian, Tremeer), and in specimens from Bossiney Haven it has become a major constituent. It is here developed in company with a pale feebly pleochroic epidote, chlorite, titanite and magnetite in a crushed vesicular rock containing abundant calcite. The biotite is strongly pleochroic from straw yellow to olive green, and is uniaxial.

Intrusive "Greenstones".

The outcrops of the intrusive igneous rocks of Michaelstow and of the long strip on the north-east of the Bodmin Moor granite lie for the greater part within the aureole of metamorphism. The intrusions at Laneast and Two Bridges, however, are at an average distance of two and a half miles from the outcrop of the granite. Mention has been made of the evidence that these intrusions were formed before the crustal movements which accomplished much of the metamorphism under discussion. Examples from well outside the aureole, such as the well-known rock of Two Bridges, are fairly fresh ophitic dolerites. The augite, however, is partially replaced by chlorite. The felspar is albite, enclosing abundant chlorite, epidote and prehnite. Iron ores, originally ilmenite, are extensively converted to leucoxene. The greenstones within the aureole show the mineralogical reconstitution too familiar to need detailed description; the ferromagnesian recrystallizes as fibrous actinolite, and the titanium enters into well-crystallized granular sphene. The chloritic alteration characteristic of ferromagnesians affected by dynamic metamorphism at low temperatures is here nowhere seen.

Superposed Thermal Metamorphism in Devonian Slates.

The contact action of the granite, apart from a noticeable absence of marked pneumatolytic effects, is in general very similar to that well known from the aureoles of the other Permo-Carboniferous intrusions of Devon and Cornwall. A few special points, however, arise from the fact that the structure and mineralogical composition of the unaltered rock were not those of a normal sedimentary series. In moderately altered specimens spotting of two different types can be seen; in rocks not markedly schistose it is of normal thermal type, but if the original rock was highly schistose the structure tends to be preserved and even increased by the formation of the contact-minerals. For example, in specimens from the lane above Altarnun, west of Trewen, red-brown thermal biotite is forming in small flecks chiefly concentrated around iron-ores, and the faint spots are of the normal kind. In specimens of silvery schist from the cart-track north of Lanlavery Rock, Davidstow Moor, the newly-formed biotite has followed the schistosity and the apparent spotting is more of the nature of a relict eye-structure. In rocks originally containing porphyroblastic chlorite another method of formation of biotite is seen; instead of the initial formation of scattered small crystals, the existing chlorite is converted to biotite with an almost complete preservation of the original relationships. Specimens from near Trefrew and from the lane south of Twelve Mens Moor, show red-brown biotite in parallel intergrowth with colourless mica exactly reproducing the features of the chlorite-white-mica porphyroblasts of the unaltered phyllites.

It has not been possible to trace in detail the destruction of the chloritoid owing to the lack of sufficient exposures. Good crystals are present in many of the rocks containing andalusite, an observation in conformity with that of the presence of chloritoid in the chiastolite rocks of the Skiddaw aureole. It is also present in rocks containing abundant biotite and pinite after cordierite; doubtless it eventually contributes to the formation of further cordierite. The highest temperature equivalents, in the form of xenolithic inclusions in the granite, have been recently described by Dr. Ghosh (1927) and include andalusite-spinel-cordierite hornfelses.

IV. Discussion and Comparison.

In the earlier portion of this paper an attempt was made to lay down a limit, beyond which it is held the granite has exerted no important effects on the country-rock. Petrological descriptions of the phyllites and schists from beyond this limit have shown that the rocks of this area have undergone considerable mineralogical reconstitution in comparison with normal representatives of Upper Devonian sediments and lavas. It remains to discuss the nature and causes of these changes, and to compare the rock types with those of other areas.

The sediments are chiefly characterized by the development, often in porphyroblasts, of white mica, chlorite, and chloritoid. The recrystallization of the two former minerals is one of the most marked changes in the early stages of regional dynamic metamorphism of pelitic rocks, that of chlorite indeed being the index by which the lowest grade has been determined in laying down the metamorphic zones in the Scottish Highlands. Chloritoid is a mineral of far more restricted distribution, and the exact conditions governing its formation are still attended with considerable uncertainty. In sediments of appropriate composition, however (supra p. 548), its formation may begin almost as early as that of chlorite, though its field of stability extends up through the biotite and garnet zones (Tilley, 1925, pp. 317–8; Phillips, 1928, p. 504) into that of kyanite. Niggli (1912) has discussed the parageneses of chloritoid extensively on physico-chemical principles in the light of the phase rule, and shows how, even in the same complex where there is little difference of chemical composition, rocks free from chloritoid and rich in it may be formed. In a variable series such as the banded sediments of North Cornwall there is still greater reason for capricious distribution. The localities which have yielded characteristic chloritoid-phyllites show no relationship to the outcrop of the granite, but do follow in a general way the major tectonic features of folding and overthrusting.

The sporadic appearance of garnet is explained by the manganese-bearing character of this mineral. Almandine is an index mineral in pelitic schists which does not appear until after the abundant development of biotite, but it has been shown in a number of cases that a garnet containing a fair proportion of spessartite can arise much earlier. This is true of the ottrelite-phyllites of the Ardennes, has been abundantly confirmed by Goldschmidt in the Stavanger district (1920, p. 61), and more recently has been described by Dr. Tilley in the Start area, (1923, p. 198), where the spessartite-content of the garnet is 12·8 per cent. As noted above, this is also the proportion of manganese-garnet present in the Cornish mineral.

The igneous horizons show the formation of chlorite, albite and epidote over most of the area ; hornblende, often with characteristic porphyroblastic habit, appears in places, and in the west a green biotite is common. All these changes can be paralleled by examples from the Green Beds of the Highlands and the Start. The original spilites were low in potash, and owing to the presence of abundant calcite there was sufficient lime to contribute to the early formation of amphibole, which under such conditions appears in the Green Beds before garnet and considerably below the grade characterized by the appearance of biotite in pelites. The formation of biotite in company with epidote,[1] in place of hornblende, suggests of necessity a higher potash content in the original rock, though little is known of the composition of the type of green mica now in question. No analysis appears to exist of such a mica from a crystalline schist. Most analyses of green micas are of well-crystallized material from veins and dykes associated with igneous rocks of alkaline affinities and are high in soda. A green mica from a hornfels, analysed by Professor Sollas,[2] contained 16·5 per cent. MnO. Dr. Tilley has suggested in the case of the Start (1923, p. 201) that the more potassic character is an indication of a tuff containing admixed material rather than a lava, and though the Upper Devonian activity is essentially spilitic in character there are associated fragmental deposits in other areas, as for instance many of the Devonian schalsteins. The entry of hornblende in such a rock would mark a much higher grade—in many of the similar horizons among the Green Beds it does not appear until after garnet.

Comparison of this area with the Start has been made more than once by earlier writers, but with reservations. In 1903 Parkinson wrote that the only indubitable instances of contact-metamorphism were from the south-eastern part of the Davidstow district, but if contact were not responsible for the changes in the Volcanic Series he was at a loss to assign a cause ; but the metamorphism recalled in one or two instances the schists of the Start. Mr. Dewey, in the discussion on Dr. Tilley's paper (1923) compared the actinolite-chlorite-epidote-albite schists from the north of Trebarwith with those of the Start, but suggested at that time that the biotite was a thermal product due to the action of the granite. It is the contention of this paper that the two areas are exactly comparable in their metamorphism; an original series of sediments and intercalated igneous horizons have undergone regional metamorphism, of insufficiently high grade to cause the appearance of biotite in pelitic rocks. In the more sensitive green beds, however, stages of increasing metamorphism can be traced. Only in the sporadic appearance of chloritoid is the North Cornish area differentiated from its neighbour, and this is to be accounted for by a difference of composition between the Upper Devonian sediments and the older parent-rocks of the Start schists. The whole assemblage, in fact, of " Phyllite, Chloritschiefer, Chloritoidschiefer " is quoted by Grubenmann (Grubenmann-Niggli, 1924, p. 399) as " typical representatives of epimetamorphism, the upper zone of metamorphism of the crystalline schists ".

---

[1] Cf. Tilley, C. E., *Q.J.G.S.*, 1925, lxxxi, p. 103.

[2] Sollas, W. J., *Sci. Proc. Roy. Dublin Soc.*, 1891–92, N.S., 7, p. 52.

V. Summary.

The geological succession and structure of the district are briefly summarized. Evidence of stress conditions becomes increasingly abundant as one passes from south to north towards the boundary of the Carboniferous.

The thermal alteration due to the Bodmin Moor granite is definitely delimited by tracing the outer limit of spotting in normal pelitic sediments.

Petrographical study of phyllites from outside this limit shows considerable mineralogical reconstruction in the sediments, with crystallization of white mica, chlorite and chloritoid; in some instances garnet is developed. The distribution of these types shows no relationship to the granite outcrop, but accords with the main structural features of the area.

Analogous changes are prominent in the igneous horizons, with the formation of schists of the general type of prasinite.

Within the aureole thermal effects can be traced superposed on the earlier dynamic changes.

From these lines of inquiry it is concluded that many of the changes in the phyllites, notably the formation of porphyroblastic white mica, chlorite and chloritoid, hitherto ascribed with greater or less finality to the action of the granite, are due to an earlier dynamic metamorphism.

VI. Acknowledgments.

The author is indebted to Sir J. S. Flett, Director of the Geological Survey of Great Britain, for permission to examine the slices from this area in the Survey Collection, and to Dr. H. H. Thomas for affording every aid in so doing. Mr. H. Dewey has placed at the author's disposal his intimate knowledge of the area, and granted opportunities for personal discussion of several points. During the laboratory investigation in Cambridge the assistance afforded by Dr. A. Harker has been a constant source of encouragement.

WORKS CITED IN THE TEXT.

1847. PATTISON, S. R. "On the Geology of the Tintagel District": *34th Ann. Rep. Roy. Geol. Soc. Cornwall*, pp. 3–12.

1865. —— "Geology of the Tintagel District": *Trans. Roy. Geol. Soc. Cornwall*, vii, p. 3.

1889. HUTCHINGS, W. M. I: "Notes on Altered Igneous Rocks of Tintagel, North Cornwall": GEOL. MAG., pp. 53–59, 101–9.

—— II: "On the occurrence of Ottrelite in the Phyllites of North Cornwall": Idem., pp. 214–20.

1903. PARKINSON, J.: "Geology of the Tintagel and Davidstow District": *Q.J.G.S.*, lix, pp. 408–28.

1909. DEWEY, H. "On Overthrusts at Tintagel (North Cornwall)": *Q.J.G.S.*, lxv, pp. 265–80.

1910. REID, C., et. al. "Geology of the Country around Padstow and Camelford": *Mem. Geol. Surv. Eng. and Wales*, Sheets 335 and 336.

1911. —— "Geology of the country around Tavistock and Launceston": Idem, sheet 337.

1911. DEWEY, H., and FLETT, J. S. "British Pillow-lavas and the Rocks associated with them": GEOL. MAG., pp. 202–9 and 241–8.

1914. DEWEY, H. "The Geology of North Cornwall": *Proc. Geol. Ass.*, xxv, pp. 154–79.

1920. GOLDSCHMIDT, V. M. "Die Injektionsmetamorphose im Stavanger-Gebiete": *Vidensk. Selsk. Skrift. M. N. Kl.*, No. 10.

1923. TILLEY, C. E. "Petrology of the metamorphosed rocks of the Start Area": *Q.J.G.S.*, lxxix, pp. 172–204.

1924. GRUBENMANN, U., and NIGGLI, P. *Die Gesteinsmetamorphose.* Berlin, 1924.

1925. TILLEY, C. E. "Petrographical Notes on some Chloritoid Rocks": GEOL. MAG., lxii, pp. 309–19.

1927. GHOSH, P. K. "Petrology of the Bodmin Moor Granite, Cornwall": *Min. Mag.*, xxi, pp. 301–6.

1928. PHILLIPS, F. C. "Petrological Notes on three Rock-types from the Shetland Islands": GEOL. MAG., LXV, pp. 500–7.

REVIEWS.

Seventh Annual Report of the Secretary for Mines for the year ended 31st December, 1927, with the Annual Report of H.M. Chief Inspector of Mines. Stationery Office, 1928. Price, 5*s.* 6*d.*

It is very interesting to compare this present report of the Mines Department and the documents issued with the same object in the days before the war, for example those for the year 1913, the last of the old cumbrous style. Changes and improvements are noticeable not only in the general format of the reports, but also in the arrangement of the contents. The old issues were voluminous but uncomfortable publications in three separate parts of a large foolscap size, printed in very large type, which would not fit into any library shelves and invariably got lost on a dump-heap in some odd corner: the present issue is a handy octavo volume, very convenient for any style of filing. But a still more noticeable improvement is in the arrangement of the contents. Formerly this was purely alphabetical, so that the most incongruous things were brought together: now the different mineral products of the country are arranged according to their uses in industry, a much more logical arrangement, which greatly facilitates easy reference. There are now five sections and appendices: the first section deals entirely with coal, the second is entitled "Other Mining and Quarrying Industries", while the rest deal with the legal, sociological, and hygienic sides of mining administration and include the annual report of the Chief Inspector of Mines.

The second section, which is the work of Dr. F. H. Hatch, is of most concern to the readers of the Geological Magazine. The subdivisions here adopted are as follows: iron ore and ironstone (the classification is now geological rather than by Act of Parliament, as formerly, which led to ridiculous results); tin; lead; zinc; minerals used in iron and steel making; minerals used for china, pottery, and glass; minerals used for building, road-making, etc.; other minerals. (Some of these titles are here slightly abbreviated.) It must be confessed that most of the statistics of these industries here given make melancholy reading when compared with those of pre-war days. Thus, for example, in Cleveland the output of iron ore was 2,530,000 tons in 1927, as compared with about 6,000,000 tons in 1913. On the other hand, the rest of the Jurassic ironstone from the Midlands actually shows an increase of half a million tons over 1913 (7,013,000 tons against 6,555,000 tons). The output of Coal-measure ironstone in 1927 was 298,000 tons. These figures must surely at last dispose of the fable so beloved by economists and the writers of school geographies that British iron ores are mined in the coalfields.

In view of the past history of British mining, it is noteworthy that the item "copper" does not appear at all in the table of contents, although a few tons of copper precipitate and dressed copper ore are recorded, in a subsidiary table, from Cornwall, Devon, Lancashire, and Anglesey. From 1873 to 1882 the decennial average for dressed copper ore was 64,733 tons; in 1926 the output was 155 tons and in 1927 it was 270 tons. This seems to have come from Coniston. The output of tin, lead, and zinc ores shows a small increase over any year since 1920. Many "non-metallic" minerals, such as barytes and gypsum, have maintained or even considerably increased their production, and the same is mainly true of fluxes, refractories, moulding sands, and so forth. It should be noted that owing to the disturbed industrial character of the year 1926, comparisons of the year 1927 are wisely made with 1925, as giving a truer picture of relative conditions.

THE OIL-SHALES OF THE LOTHIANS. Third edition, 1927. By R. G. CARRUTHERS, W. CALDWELL, E. M. BAILEY, and H. R. J. CONACHER. *Mem. Geol. Survey, Scotland*, pp. viii + 274, with 12 plates and 75 text-figures. Edinburgh, 1927. Price 5*s.* 6*d.*

THE third edition of this well-known work follows the lines of the two earlier ones, but contains a good deal of new material. The section dealing with the Chemistry and Technology of the Oil-Shales, which was contributed to the previous editions by the late D. R. Steuart, has been re-written by Mr. E. M. Bailey, while a new section, describing the development of the industry and the various vicissitudes it has passed through since its inception about 1858 has been added by Mr. H. R. J. Conacher. Mr. W. Caldwell has revised his account of the methods of working the Oil-Shales and has brought this section up to date. These contributors are on the staff of Scottish Oils, Ltd., and are recognized experts on the subjects with which they deal. The geological portion of the memoir, though it remains substantially as in the 1912 edition, has where necessary been added to and corrected. The memoir is illustrated by 75 text figures and 12 plates, including a remarkably clear coloured geological map of the main Lothians shale-fields and a sheet of comparative vertical sections showing the sequence of strata in different areas.

CATALOGUE OF THE PONTIAN BOVIDAE OF EUROPE IN THE DEPARTMENT OF GEOLOGY. By DR. G. E. PILGRIM and A. T. HOPWOOD. Pp. viii + 106, with nine plates and three text-figures. London: Printed by order of the Trustees of the British Museum. 1928.

THIS memoir, as Dr. Bather explains in the preface, is for the most part the work of Dr. Pilgrim, of the Geological Survey of India, and was done during his leave of absence. The issue of Dr. Andrews' work on the similar collections at Stuttgart and Vienna rendered it desirable to revise what Dr. Pilgrim had written, and since he had returned to India Dr. Bather entrusted the revision to Mr. Hopwood, with whose conclusions Dr. Pilgrim on his subsequent return to England was able wholly to concur. The joint labours of the two authors have resulted in the production of a memoir on the European Cavicornia which is well worthy of the Museum. The arrangement of the groups or sub-families is that of Schlosser in the revised edition of Zittel except that *Helicotragus* is placed in the *Gazellinae* instead of the *Tragelaphinae*. As the authors point out, the classification of the extinct genera of this family is exceptionally difficult, since the systematic position of many living forms is still undecided. The work consists of detailed anatomical descriptions of the specimens contained in the Museum collections, checked and supplemented by comparisons with other collections at Lausanne, Munich, Vienna, and Stuttgart.

F. H. A. M.

SOME CHARACTERISTIC FEATURES OF THE ORE DEPOSITS OF JAPAN RELATED GENETICALLY TO THE LATE TERTIARY VOLCANIC ACTIVITY. By T. KATO, *Japanese Journal of Geology and Geography*, vol. vi, 1928, pp. 31–48.

PROFESSOR KATO here gives in small compass a summary of his conclusions as to the genesis and relations of the type of ore-deposits named in the title, together with brief generalized descriptions of some important mining areas, which are very useful. He considers that these deposits were formed by pegmatite-pneumatolytic and hydro-thermal solutions, representing late stages of magmatic activity in not very deep-seated regions. They are closely related to the volcanic rocks extruded at the surface. Owing to the rapid cooling of these residual solutions the various metalliferous deposits overlap in composite veins, and complex sulphide deposits are formed by successive mineralizations in the same rocks, features characteristic of volcanic as opposed to plutonic regions.

R. H. R.

MINERALOGY. By E. H. KRAUS and W. F. HUNT. Second edition, pp. 604, with 766 figures. McGraw-Hill Co., New York and London, 1928.

THE second edition of this work has been thoroughly revised and brought up to date, some chapters being entirely reset, while a chapter on crystal structure and X-ray analysis has been added. Many of the extraordinarily numerous figures have been replaced by new ones. Some of the figures of crystal-specimens even yet do not really show anything in particular, and it may be doubted whether the portraits, mostly of eminent German mineralogists, are of much value. However, some of the pictures in the chapter on " Classification of Minerals According to Elements " are very interesting, including a big steam shovel mining rock-salt 1,130 ft. below the surface at Detroit, Michigan, and several views of American docks and railroad cars loading sulphur and iron ore. The view of a gigantic crystal of spodumene at the Etta Mine, S. Dakota, is particularly thrilling. Illustrations of this sort do in fact lend an actuality and human interest which is conspicuously lacking in most text-books of mineralogy, while the text contains a vast amount of the most valuable information as to the dry facts of the science. This is certainly a live book, and may be strongly recommended to working economic geologists.

ANNOUNCEMENTS AND INQUIRIES.

The Council of the Geological Society of London announces the receipt of a generous gift of $10,000 Dominion of Canada 4½ per cent Bonds from Mr. J. B. Tyrrell, the well-known Canadian mining geologist, for the foundation of a fund, to be known as the J. B. Tyrrell Fund, the interest of which is to be devoted to the furtherance of a knowledge of the geology of the Dominion of Canada among the geologists of Great Britain and Ireland.

The first award from this fund will be made in February, 1929, and applications are now invited from British and Irish geologists who desire to visit the Dominion of Canada for the purpose of study or research, and who require assistance in the payment of the necessary travelling and living expenses. The amount of the fund available for this award is £100. Details of the conditions governing the disbursement of this fund, and of the form of application required can be obtained from the Secretaries, The Geological Society of London, Burlington House, Piccadilly, London, W.

INDEX.

AFRICAN Rock Collections, W. C. Smith, 375.
Allorisma amotapense sp. nov., 223.
— *baldryi* sp. nov., 222.
— *barringtoni* sp. nov., 221.
— *parinasense* sp. nov., 223.
Alsace, Geology of, J. Jung, 377.
Alston Block, F. M. Trotter and S. E. Hollingworth, 433.
Ammonites, New Zealand, P. Marshall, 419.
Anderson, F. W., Skyreholme Anticline, 518.
Andrews, C. W., the late, *Elephas antiquus* from Upnor, 421.
Antiquity of Man in East Anglia, J. Reid Moir, 141.
Apatite, Dark, in some British Rocks, W. F. Fleet and F. Smithson, 6.
Astartella meridionalis sp. nov., 231.
Astronomy and Cosmogony, J. H. Jeans, 329.
Atomic volume relations in certain isomorphous series, II, A. F. Hallimond, 288, 427.
Aviculopecten bravoi sp. nov., 150.
— *multiscalptus* sp. nov., 148.
— *sullanaensis* sp. nov., 151.

BADEN-POWELL, D., Climatic Correlation of Raised Beaches, 47.
Bailey, E. B., Across Canada with Princeton, 41.
Bancroft, B. B., Unconformity at Base of the Ashgillian, 484.
Basalt Columns, Giants Causeway, Joints on Surface of, H. P. T. Rohleder, 354.
Base of the Ashgillian, Unconformity at, B. B. Bancroft, 484.
Batillaria pleurotomoides (Lam.), T. H. Rowlands, 529.
Bauxite, a Study of, T. V. M. Rao, 46.
— from Kashmir, T. V. M. Rao, 288.
Beach Gravels, Wearing of, P. Marshall, 420.
Behrend, F., Chemical Geology, 35.
Berg, G., Chemical Geology, 35.
Bertrand, Marcel, Geological work of, 474.
Biotite-bearing Greenstones, P. K. Ghosh, 46.
Bisat, W. S., Carboniferous Zones Committee Report, 43.
Black, M., "Washouts" in Estuarine Series, Yorkshire, 301.
Boswell, P. G. H., Geology of Ipswich, 38.
Boulton, W. S., Geology of the Lickey Hills, 255.
— — Red Rocks and Limestones near Birmingham, 313.
Bowie, W., Isostasy, 279.
Brachiopod Morphology, J. A. Thomson, 373.
Brade-Birks, S. G., Notes on Myriapoda, 400.
Brammall, A., Dartmoor Detritals, 95.
Breccias, S. H. Reynolds, 97.
Brighton, A. G., Middle and Upper Chalk, Cambridge District, 368.
British Honduras, Silica Lines of, L. H. Ower, 507.
Bubnoff, S. von, Process of Eruption, 424.
Bulman, O. M. B., *Odontocaulis*, 337.

CALCAREOUS Tufa in Mountain Stream at Binn, W. A. Macfadyen, 1.
Calciferous Sandstone Volcanic Rocks, N. Ayrshire, J. E. Richey, 44.
Cambrian Rocks, near the Wrekin, R. W. Pocock, 47.
Canada, E. B. Bailey, 41.
Carboniferous Limestone, Rare *Euryocrinus*, J. Wright, 246.
— — S. Wales, T. Robertson and T. N. George, 425.
— Olivine-Basalts and Mugearites, Scottish, A. G. Macgregor, 287.
— Outlier at Pen-Cerig-calch, T. N. George, 162.
— Rocks, Lanarkshire, G. Ross, 286.
— Zones Committee Report, W. S. Bisat, 43.
Carrickgollogan, Problem of, F. Smithson, 78.
Carruthers, R. G., and others, Oil-Shales of the Lothians, 558.
"Cast" and "Mould" in Palaeontology, J. Challinor, 410.

Chabot, G., Plateau region of Central Jura, 474.
Chalk and Marl in the Moluccas, T. S. Hok, 328.
— Middle and Upper, Cambridge District, A. G. Brighton, 368.
Chalky Boulder-Clay, Wembley Park, H. G. Mantle, 481.
Challinor, J., Curious Rock-Marks, Transbaikalia, 241.
— — Shelly Band in Graptolitic Shales, 364.
— — Terms "Cast" and "Mould" in Palaeontology, 410.
Chapman, F., Triassic Plants from Victoria, 191.
Charlesworth, J. K., Origin of Relict Fauna, Lough Neagh, 212.
Chemical Geology, F. Behrend and G. Berg, 35.
Chert Deposits, Ecuador, G. Sheppard, 343.
Chhibber, H. L., Tertiary Volcanics, Burma, 40.
Clapham-Morden Railway Extension, Geology of, A. G. Davis, 332.
Classification of Eruptive Rocks, S. J. Shand, 192.
Climatic Correlation of Raised Beaches, D. Baden-Powell, 47.
Clinopistha (?) *parinasensis* sp. nov., 230.
Coal in Great Britain, W. Gibson, 34.
— Measures, Lancashire, G. Hickling, 330.
— — Marine Horizons, E. Dix and A. E. Trueman, 356.
— — S. Wales, Linnaeite in, W. E. Howarth, 517.
Coast Sandstone, Syria, Pipes in, A. E. Day, 412.
Codazzi, R. Ll., Minerals of Colombia, 235.
Collingridge, H., Optic Axial Angles, 428.
Comber, N. M., Scientific Study of Soil, 476.
Composite Dyke, Dumbartonshire, J. F. Scott, 379.
Continental Drift, Theory of W. A. J. M. Van der Gracht, 422.
Cooper, C. F., *Elephas antiquus* from Upnor, 421.
Cornwall, N., Metamorphism in Upper Devonian of, F. C. Phillips, 541.
Craven Lowlands, Structure of, R. G. S. Hudson, 380.
Custerite-bearing Contact Rock, California, C. E. Tilley, 371.

DARK Apatite in some British Rocks, W. F. Fleet and F. Smithson, 6.
Dartmoor Detritals, A. Brammall, 95.
Davis, A. G., Geology of Clapham-Morden Railway Extension, 332.
Davies, K. A., Geology of Country between Rhayader and Abergwesyn, 285.
Day, A. E., Pipes in Coast Sandstone of Syria, 412.
— — Tertiary Volcanics, Burma, 40.
Denmark, Geological Survey, 50.
Disciniscà ferroviae, a new Brachiopod, H. M. Muir-Wood, 332.
Discoveries in Kent's Cavern, F. Longworth-Dames, 168.
Dix, E., Marine Horizons in Welsh Coal Measures, 356.
Dominica, Island of, Geological Notes on, K. W. Earle, 169.
Dublin District, Geological Studies in, F. Smithson, 12, 78.
Dumortierite in grains, identification of, A. W. Groves, 288.
du Toit, A. L., Geological Comparison of S. America with S. Africa, 139.
— — Origin of the Dwyka Conglomerate, 240.
Dwyka Conglomerate, E. H. L. Schwarz, 244.
— — Origin of, A. L. du Toit, 240.
— — — C. G. S. Sandberg, 117, 428.

EARLE, K. W., Geological Notes on Island of Dominica, 169.
Earthquakes, Recent Scottish, G. W. Tyrrell, 378.
Eastwood, T., Geology of S. Staffordshire Coalfield, 94.
Economic Geology, W. Lindgren and others, 335.
— — Elements of, J. W. Gregory, 190.
Ecuador, Chert Deposits in, G. Sheppard, 343.
Edinburgh Geological Society, 41.
Edwards, W. N., *Glossopteris* in the Beacon Sandstone, S. Victoria Land, 323.
Ellsworth, H. V., Constant-volume Pyknometer, 192.
Emmons, W. H., Geology of Leadville, 416.
— — Igneous Intrusives, 31.

Encrinuridae, Notes on the Family of, F. R. Cowper Reed, 51.
Eocene and Pliocene Outliers, Surrey, A. W. Groves, 96.
Eruption, Process of, S. von Bubnoff, 424.
Estuarine Series, Yorkshire, "Washouts" in, M. Black, 301.
Euphoberia ferox from Coal Measures, Crawcrook, S. G. Brade-Birks, 400.
Euryocrinus, Rare, from Clitheroe, J. Wright, 246.
Eyles, V. A., Igneous Geology, C. Ayrshire, 286.

FAUNAL Horizons in Carboniferous Limestone, Vale of Clwyd, E. Neaverson, 528.
Faeröe Islands, Geology of, J. B. Simpson, 510.
Falconer, J. D., Geology of Nigeria, 430.
Fauna of Lough Neagh, Origin of Relict, J. K. Charlsworth, 212.
— Upper Carboniferous, N.W. Peru, H. D. Thomas, 215, 289.
Fifty Years of Geology, Maryland, America, 188.
Figured Fossils, National Museum of Wales, F. J. North, 193.
Fleet, W. F., Dark Apatite in some British Rocks, 6.
Fleure, H. J., Prehistoric Man, 36.
Fossil Fish from the Keuper of Nottingham, H. H. Swinnerton, 406.
— Plants from the Antartic, W. N. Edwards, 323.

GARWOOD, E. J., River Meanders, 285.
Gastrioceras amotapense sp. nov., 293.
— *browni* sp. nov., 297.
— *pacificum* sp. nov., 296.
— (?) *parinasense* sp. nov., 298.
Geological Comparison of S. America with S. Africa, A. L. du Toit and F. R. Cowper Reed, 139.
— Society: Award of Medals and Funds, 49.
Geologists' Association, 41, 95, 285, 332, 425, 426.
Geometry of Structure Lines, A. Stevens, 144.
George, T. N., Carboniferous Limestone, S. Wales, 425.
George, T. N., Carboniferous Outlier at Pen-Cerig-calch, 162.
Ghosh, P. K., Biotite-bearing Greenstones, 46.
Gibson, W., Coal in Great Britain, 34.
Glasgow Geological Society, 44, 144, 236, 286, 331, 378.
Glossopteris in the Beacon Sandstone, S. Victoria Land, W. N. Edwards, 323.
Goodchild, J. G., Prestwich's Geological Map of Europe, 235.
Gossling, F., Geology of Country Around Reigate, 426.
Grange, L. I., Geology of New Zealand, 419.
Graptolitic Shales, Shelly Band in, J. Challinor, 364.
Gregory, J. W., Elements of Economic Geology, 190.
— — Geology of Loch Lomond, 331.
Groves, A. W., Eocene and Pliocene Outliers, Surrey, 96.
— — Identification of dumortierite in grains, 288.

HADDING, Assar, Swedish Sediments, 93.
Hallimond, A. F., Atomic volume relations in certain isomorphous series, II, 288, 427.
Harwood, H. F., Age and composition of Whin Sill, 288.
Hayward, H. A., Geology of Lower Greensand around Dorking, 426.
Heavy Minerals of Granite and Contiguous Rocks, Dublin District, F. Smithson, 12.
Hickling, G., Coal Measures, Lancashire, 330.
Higgins, A. L., Phototopography, 91.
Hill-slopes, P. Lake, 108.
Hok, T. S., Chalk and Marl in the Moluccas, 328.
Hollingworth, S. E., Alston Block, 433.
Holmes, A., Age and composition of Whin Sill, 288.
— — Radioactivity and Continental Drift, 236.
Hopwood, A. T., Catalogue of Pontian Bovidae of Europe, 558.
Horne, J., Obituary notice of, 381.
Howardian Hills, Structure of, H. C. Versey, 379.
Howarth, W. E., Linnaeite in South Wales, 517.

Hudson, R. G. S., Structure of the Craven Lowlands, 380.
Hunt, W. F., Textbook of Mineralogy, 559.

IGNEOUS Geology of C. Ayrshire, V. A. Eyles, J. B. Simpson, and A. G. Macgregor, 286.
Igneous Intrusives, W. H. Emmons, 31.
Implement of Quartzite (Supposed), C. T. Trechmann, 25.
Ingham, F. T., Petrology of the Spilsby Sandstone, 96.
International Geological Congress, 49.
Ipswich, Geology of, P. G. H. Boswell, 38.
Ireland, Petrography of Triassic Sandstone of N.E., D. L. Reynolds, 448.
Irving, J. D., Geology of Leadville, 416.
Island of Dominica, Geological Notes on, K. W. Earle, 169.
Isostasy, W. Bowie, 279.

JEANS, J. H., Astronomy and Cosmogony, 329.
Joints on Surface of Basalt Columns, Giants Causeway, H. P. T. Rohleder, 354.
Jung, J., Geology of Alsace, 377.
Jura, Plateau region of Central, G. Chabot, 474.

KATO, T., Ores in Japan, 478, 559.
Kennard, A. S., Mollusca from Pleistocene Deposits, Cambridge District, 307.
Kent's Cavern, F. Longworth-Dames, 168.
King, W. B. R., Pleistocene Deposits, Cambridge District, 307.
— — Pleistocene Marine Gravels in Northants, 210.
Kraus, E. H., Textbook of Mineralogy, 559.
Krige, A. V., Changes of Sea-level in S. Africa, 236.

LABRADORITE from Ireland, Optical Orientation of, W. C. Smith, 192.
Lake, P., On Hill-slopes, 108.
Lane, A. C., Till on Overthrust Gravels, 8.
Leached Copper Outcrops, A. Locke, 33.
Leadville, Geology of, S. F. Emmons, J. D. Irving, and C. F. Loughlin, 416.
Leda browni sp. nov., 216.
Lickey Hills, Geology of, W. S. Boulton, 255.
Limestone contact-rock bearing Custerite, C. E. Tilley, 371.
Lindgren, W., Magmatic Ore Deposits, 31.
— — Mineral Deposits, 415.
Linnaeite in Coal-measures, S. Wales, W. E. Howarth, 517.
Liverpool Geological Society, 528.
Loch Lomond, Geology of, J. W. Gregory, 331.
Locke, A., Leached Copper Ore-crops, 33.
London Clay of Bognor, E. M. Venables, 332.
Longworth-Dames, F., Kent's Cavern, 168.
Loughlin, C. F., Geology of Leadville, 416.
Lower Carboniferous Rocks, Pennines, F. M. Trotter and S. E. Hollingworth, 433.
— — of the Skyreholme Anticline, F. W. Anderson, 518.
— Greensand around Dorking, Geology of, H. A. Haywood, 426.

MACFADYEN, W. A., Calcareous Tufa in a Mountain Stream at Binn, 1.
Macgregor, A. G., Igneous Geology of C. Ayrshire, 286.
— — Scottish Carboniferous Olivine-Basalts and Mugearites, 287.
Macgregor, M., Scottish Carboniferous Stratigraphy, 45.
Magmatic Ore Deposits, W. Lindgren, 31.
— Origin of Ores, R. H. Rastall, 270, 479.
— — — H. C. Sargent, 431.
Manchester Geological Association, 284.
— — — Journal of (1925–6), 234.
Mangaia, Geology of, P. Marshall, 420.
Mantle, H. G., Chalky Boulder-Clay at Wembley Park, 481.
"March Gravels" in Northants., J. E. Marr and W. B. R. King, 210.

Marine Horizons, Welsh Coal Measures, E. Dix and A. E. Trueman, 356.
Marr, J. E., Pleistocene Deposits, Cambridge District, 307.
— — Pleistocene Marine Gravels in Northants., 210.
Marshall, P., Ammonites in New Zealand, 419.
— — Geology of Mangaia, 420.
— — Wearing of Beach Gravels, 420.
Marwick, J., Tertiary Mollusca, Chatham Islands, 420.
Metamorphism in the Upper Devonian, N. Cornwall, F. C. Phillips, 541.
Metamorphosed Nodular Shale, L. R. Wager, 88.
Meteorites, Appendix to the Brit. Mus. Catalogue, G. T. Prior, 188.
Mesozoic Mammalia, G. G. Simpson, 421.
Middle and Upper Chalk, Cambridge District, A. G. Brighton, 368.
Mineral Deposits, W. Lindgren, 415.
— names, Eleventh list of new, L. J. Spencer, 427.
Mineralogical Society, 46, 191, 288, 427.
Mineralogy, Textbook of, E. H. Kraus and W. F. Hunt, 559.
Minerals of Colombia, R. Ll. Codazzi, 235.
— of New Zealand, P. G. Morgan, 420.
Moir, J. Reid, Antiquity of Man in East Anglia, 141.
Mollusca, Pleistocene Deposits, Cambridge District, A. S. Kennard and B. B. Woodward, 307.
— Post-Glacial Fossil, at Winnipeg, A. Mozley, 267.
Monticellite - nepheline - basalt from Tasmania, C. E. Tilley, 29.
Moor, C. G., Tin Mining, 478.
Morgan, P. G., Minerals of New Zealand, 420.
— — Obituary notice of, 333.
Mozley, A., Post-Glacial Fossil Mollusca at Winnipeg, 267.
Mud-Volcano in the Caucasus, F. Oswald, 494.
Muir-Wood, H. M., A New Brachiopod, *Discinisca ferroviae*, 332.
Myriapoda, Notes on, S. G. Brade-Birks, 400.

NEAVERSON, E., Faunal Horizons, Vale of Clwyd, 528.
Nels, L. T., Geology of Country round Vredefort, 141.
New Zealand Geology, L. I. Grange, 419.
Nigeria, Geology of, J. D. Falconer, 430.
North, F. J., Figured Fossils in the National Museum of Wales, 193.
North American Triassic Invertebrates, J. P. Smith, 282.
— — — — J. B. Reeside, 283.

OBITUARY :—
—Sir Aubrey Strahan, 239.
—J. Allan Thomson, 333.
—Percy Gates Morgan, 333.
—Wilhelm von Branca, 334.
—John Horne, 381.
Odontocaulis Lapworth, a synonym of *Callograptus* Hall, O. M. B. Bulman, 337.
Oil-Shales of the Lothians, R. G. Carruthers and others, 558.
Ore-deposits of Malaya, J. B. Scrivenor, 417.
Ores in Japan, T. Kato, 478, 559.
— Magmatic Origin of, R. H. Rastall, 270.
Optic Axial Angles, H. Collingridge, 428.
Origin of the Relict Fauna of Lough Neagh, J. K. Charlsworth, 212.
Oswald, F., Mud-Volcano in the Caucasus, 494.

PALAEOBOTANY, Hirmer, 142.
Peake, H., Prehistoric Man, 36.
Pen-Cerig-calch, Carboniferous Outlier at, T. N. George, 162.
Peruvian Upper Carboniferous Fauna, H. D. Thomas, 146.
Phillips, F. C., Rocks of the Shetland Islands, 500.
— — Metamorphism in N. Cornwall, 541.
Phototopography, A. L. Higgins, 91.
Pilgrim, G. E., Catalogue of the Pontian Bovidae, 558.
Pinfold, E. S., Tertiary Volcanics in Burma, 40.
Pipes in Coast Sandstone of Syria, A. E. Day, 412.
Place-names of mineral-localities, Central Europe, L. J. Spencer, 427.
Platform in the London Basin, S. W. Wooldridge, 41.

Pleistocene Deposits, Cambridge District, J. E. Marr, and W. B. R. King, 307.
— Marine Gravels in Northants., J. E. Marr and W. B. R. King, 210.
Pliocene, Alleged, of Bucks and Herts, R. L. Sherlock, 425.
— and Pleistocene Terraces, K. S. Sandford, 477.
Plutonic Intrusions of S.W. Scotland, J. F. Scott, 379.
— — Southern Uplands East of the Nith Valley, F. Walker, 153.
Pocock, R. W., Cambrian Rocks near the Wrekin, 47.
Pontian Bovidae of Europe, Catalogue of, G. E. Pilgrim and A. T. Hopwood, 558.
Post-Glacial Fossil Mollusca at Winnipeg, A. Mozley, 267.
Potarite, a new mineral, British Guiana, L. J. Spencer, 191.
Practical Geology, R. Sokolt, 40.
Prehistoric Man, H. Peake and H. J. Fleure, 36.
Prestwich's Geological Map of Europe, W. Topley and J. G. Goodchild, 235.
Prior, G. T., Appendix to the Brit. Mus. Catalogue of Meteorites, 188.
Pronocites (?) *peruvianus* sp. nov., 291.
Pyknometer for Spec. Gravity Determination, H. V. Ellsworth, 192.

QUARTZITE Implement (Supposed), C. T. Trechmann, 25.

RADIOACTIVITY and Continental Drift, A. Holmes, 236.
Raeburn, C., Tinfields of Nigeria, 191.
Ramann, E., Evolution and Classification of Soils, 476.
Rao, T. V. M., Bauxite, 46.
— — — from Kashmir, 288.
Rastall, R. H., Magmatic Origin of Ores, 479.
Red Rocks and Limestones near Birmingham, W. S. Boulton, 313.
Reed, F. R. C., Notes on the Family of Encrinuridae, 51.
— — Palaeontological contribution to Geol. Comparison of S. America with S. Africa, 139.
Reeside, J. R., N. American Triassic Invertebrates, 283.
Reigate, Geology of Country around, F. Gossling, 426.
Report, Secretary of Mines, 1928, 557.
Reynolds, D. L., Petrography of Triassic Sandstone, N.E. Ireland, 448.
— S. H., Breccias, 97.
Rhayader and Abergwesyn, Geology of Country between, K. A. Davies, 285.
Richardson, L., Wells and Springs of Somerset, 377.
— — — — Warwickshire, 475.
Richey, J. E., Calciferous Sandstone Volcanic Rocks, N. Ayrshire, 44.
River Meanders, E. J. Garwood, 285.
Robertson, T., Carboniferous Limestone, S. Wales, 425.
— — Siluro-Devonian Junction in England, 385.
Robson, G. C., Species Problem, 283, 430.
Rock Groups of Jersey, A. K. Wells and S. W. Wooldridge, 42.
Rock-marks, Curious, from Transbaikalia, J. Challinor, 241.
Rocks of the Shetland Islands, F. C. Phillips, 500.
Rohleder, H. P. T., Joints on Surfaces of Basalt Columns, Giants Causeway, 354.
Ross, G., Carboniferous Rocks, Lanarkshire, 286.
Rowlands, T. H., *Batillaria pleurotomoides*, 529.

SANDBERG, C. G. S., Origin of the Dwyka Conglomerate, 117, 428.
Sandford, K. S., Pliocene and Pliostocene Terraces, 477.
Smith, B., Geology of the Country around Wrexham, 92.
— J. P., N. American Triassic Invertebrates, 282.
— W. C., African Rock Collections, 375.
— — Optical Orientation of Labradorite, 192.
Smithson, F., Dark Apatite in some British Rocks, 6.
— — Geological Studies in Dublin District, 12, 78.
Sokolt, R., Practical Geology, 40.
Solenomorpha equatorialis sp. nov., 229.
Solenocheilus (?) *australis* sp. nov., 291.
Soil Microbiology, S. A. Waksman, 476.
Soil, Scientific Study of, N.M. Comber, 476.

Soils, Evolution and Classification of, E. Ramann, 476.
Species Problem, G. C. Robson, 283, 430.
Specific gravities of minerals, L. J. Spencer, 46.
Spencer, L. J., Eleventh list of new mineral names, 427.
— — Place-names of mineral-localities, Central Europe, 427.
— — Potarite, a new mineral discovered in British Guiana, 191.
— — Specific gravities of minerals, 46.
— — South African occurrences of willemite, 46.
Spilsby Sandstone, Petrology of, F. T. Ingham, 96.
Spirorbis Limestones and Red Rocks near Birmingham, W. S. Boulton, 313.
"Spotted" Metamorphic Rock, L. R. Wager, 88.
Staffordshire, South, Coalfield, Geology of, T. H. Whitehead and T. Eastwood, 94.
Staffs. and Salop, Geology of, T. H, Whitehead, E. E. L. Dixon. R. W. Pocock, T. Robertson, T. C. Cantrill, 33.
Stamp, L. D., Siluro-Devonian Junction in England, 479.
— — Tertiary Volcanics in Burma, 40.
Stevens, A., Geometry of Structure Lines, 144.
Strahan, Sir Aubrey, Obituary notice of, 239.
Straw, S. H., Siluro-Devonian boundary in Wales, 284.
Sanguinolites (?) *amotapensis* sp. nov., 224.
— *deportatus* sp. nov., 229.
— *insolitus* sp. nov., 228.
— *peruvianus* sp. nov., 225.
Sargent, H. C., Magmatic Origin of Ores, 431.
Schwarz, E. H. L., Dwyka Conglomerate, 244.
Scott, J. F., Composite Dyke, Dumbartonshire, 379.
— — Plutonic Intrusions, S.W. Scotland, 379.
Scottish Carboniferous Stratigraphy, M. Macgregor, 45.
— Plutonic Intrusions, F. Walker, 153.
Scrivenor, J. B., Ore-Deposits of Malaya, 417.
Sea-level in S. Africa, Changes of, A. V. Krige, 236.
Semionotus metcalfei sp. nov., 407.
— a New Species from the Keuper of Nottingham, H. H. Swinnerton, 406.
Shand, S. J., Classification of eruptive rocks, 192.
Shelly Band in Graptolitic Shales, J. Challinor, 364.
Sheppard, G., Chert Deposits in Ecuador, 343.
Sherlock, R. L., Alleged Pliocene of Bucks and Herts, 425.
Shetland Islands, Rocks of the, F. C. Phillips, 500.
Shugo, a Mud-Volcano in the Caucasus, F. Oswald, 494.
Silica Lines of British Honduras, L. H. Ower, 507.
Siluro-Devonian boundary in Wales, S. H. Straw, 284.
— — Junction in England, T. Robertson, 385.
— — — — L. D. Stamp, 479.
Simmons, W. C., Geological Survey of Uganda, 96.
Simpson, G. G., Mesozoic Mammalia, 421.
— J. B., Geology of the Faeröes, 510.
— — Igneous Geology of Ayrshire, 286.
Skyreholme Anticline, F. W. Anderson, 518.
Swedish Sediments, Assar Hadding, 93.
Swinnerton, H. H., A New Species of *Semionotus*, 406.

TERTIARY Mollusca, Chatham Island, J. Marwick, 420.
— Volcanics in Burma, E. S. Pinfold, A. E. Day, L. D. Stamp, and H. L. Chhibber, 40.
Thomas, H. D., Upper Carboniferous Fauna, N.W. Peru, 146, 215, 289.
Thomson, J. A., Brachiopod Morphology, 373.
— — Obituary notice of, 333.
Till on Overthrust Gravels, A. C. Lane, 8.
Tilley, C. E., Custerite-bearing Contact Rock from California, 371.
—Monticellite-Nepheline-Basalt from Tasmania, 29.
Tin Mining, C. G. Moor, 478.
Tinfields of Nigeria, C. Raeburn, 191.
Tomkeieff, S. I., Petrology of Whin Sill, 428.
Topley, W., Prestwich's Geological Map of Europe, 235.

Transbaikalia, Curious Rock-Marks from, J. Challinor, 241.
Trechmann, C. T., Supposed Quartzite Implement, 25.
Triassic Plants from Victoria, F. Chapman, 191.
— Sandstone, N.E. Ireland, Petrograph of, D. L. Reynolds, 448.
Trotter, F. M., Alston Block, 433.
Trueman, A. E., Marine Horizons in Welsh Coal Measures, 356.
Tufa, Calcareous, in a Mountain Stream at Binn, W.A., Macfadyen, 1.
Tyrrell, G. W., Recent Scottish Earthquakes, 378.

UGANDA Geological Survey, Report of, W. C. Simmons, 96.
Unconformity at Base of Ashgillian in Bala District, B. B. Bancroft, 484.
Upnor Elephant, C. W. Andrews, the late, and C. F. Cooper, 421.
Upper Carboniferous Fauna from N.W. Peru, H. D. Thomas, 146, 215, 289.

VAN DER GRACHT, W. A. J. M., Theory of Continental Drift, 422.
Venables, E. M., London Clay of Bognor, 332.
Versey, H. C., Structure of the Howardian Hills, 379.
von Branca, Wilhelm, Obituary notice of, 333.
Vredefort, Geology of Country round, L. T. Nels, 141.

WAGER, L. R., Metamorphosed Nodular Shale, 88.
Waksman, S. A., Soil Microbiology, 476.
Wales, Figured Fossils in the National Museum, F. J. North, 193.
Walker, F., Plutonic Intrusions of the Southern Uplands, 153.
" Washouts " in Estuarine Series, Yorkshire, M. Black, 301.
Wedd, C. B., Geology of the Country around Wrexham, 92.
Wells, A. K., Rock Groups of Jersey, 42.
Wells and Springs of Somerset, L. Richardson, 377.
— — Warwickshire, L. Richardson, 475.
Wembley Park, Chalky Boulder-Clay at, H. G. Mantle, 481.
Whin Sill, age and composition of, A. Holmes and H. F. Harwood, 288.
— — Petrology of, S. I. Tomkeieff, 428.
Whitehead, T. H., Geology of S. Staffordshire Coalfield, 94.
— — and others, Geology of Staffs and Salop, 33.
Willemite, South African occurrence of, L. J. Spencer, 46.
Wills, L. J., Geology of the Country around Wrexham, 92.
Wrexham, Geology of the Country around, C. B. Wedd, B. Smith, and L. J. Wills, 92.
Wright, J. Rare *Euryocrinus* from Clitheroe, 246.
Woodward, B. B., Mollusca from Pleistocene Deposits, Cambridge District, 307.
Wooldridge, S. W., Rock Groups of Jersey, 42.
— — The 200 ft. Platform in the London Basin, 41.

YORKSHIRE Geological Society, 43, 379.

ZANZIBAR, Geology of, 188.

Stephen Austin & Sons, Ltd., Printers, Hertford.